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ABSTRACT

FOUNDATIONS is a monograph series intended for those working to better science, mathematics, and technology education in the United States. This volume examines opportunities and challenges for those on the front lines of science education in elementary and middle schools. Designed as a resource for teachers and administrators who have not yet implemented a program of inquiry-based science education, this volume serves neither as a textbook nor as the final word on the subject. It is rather a short introduction for those beginning the complex and difficult journey of science education reform based on the experiences of educators working in the field today. Chapters include: (1) "The Challenge and Promise of K-8 Science Reform"; (2) "A Vision of Effective Science Education"; (3) "Planning for Change"; (4) "Leadership"; (5) "Curriculum, Instruction, and Assessment"; (6) "Professional Development"; (7) "Financing Science Education Reform"; (8) "Collaborators in Reform"; (9) "Equity"; and (10) "Postscript." The appendix includes resources for science education reform. (JRH)

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VOLUME 1

ED 407 245

FOUNDATIONS

A monograph for professionals in science, mathematics, and technology education

The Challenge and Promise of K-8 Science Education Reform

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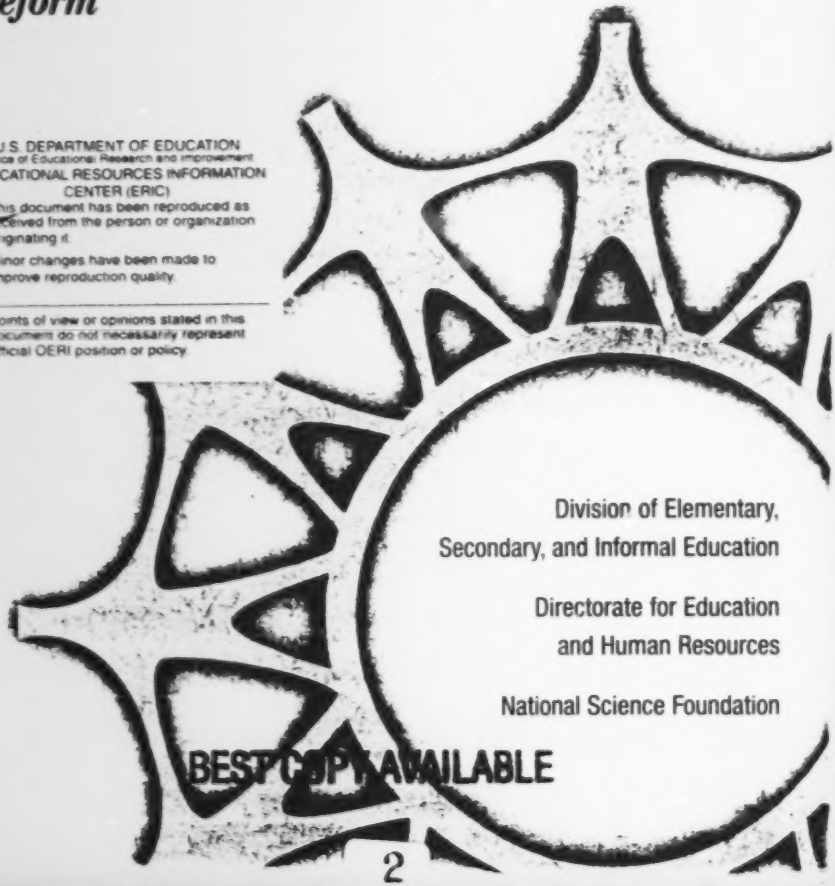

Division of Elementary, Secondary, and Informal Education

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A monograph for professionals in science, mathematics, and technology education

The Challenge and Promise of K-8 Science Education Reform

Division of Elementary, Secondary, and Informal Education

Directorate for Education
and Human Resources

National Science Foundation

About Foundations

Foundations is a monograph series published by the National Science Foundation's Division of Elementary, Secondary, and Informal Education (ESIE) in conjunction with the Division of Research, Evaluation and Communication (REC) to serve those working to better science, mathematics, and technology education in this nation. Foundations supports education reform by communicating lessons that have been learned from ESIE projects and activities to others in the field who may use and adapt them to build effective educational improvement strategies in their own classrooms and communities. Like the foundation of a schoolhouse, home, or other place of learning, the strength of what is above ground depends on the structural soundness of what lies below. Foundations will unearth the strategies that enable effective educational improvement at the K-12 level to take place. Welcome to Foundations...

In This Volume

Foundations examines opportunities and challenges for those at the front line of science education in elementary and middle schools. Designed as a resource for teachers and administrators who have not yet implemented a program of inquiry-based science education, this volume serves neither as a textbook nor as the final word on the subject. It is rather a short introduction for those beginning the complex and difficult journey of science education reform based on the experiences of educators working in the field today.

A Letter from the Division Director

Dear Friends and Colleagues:

Our mission in the Division of Elementary, Secondary, and Informal Education is to improve teaching and learning in school settings—prekindergarten through the 12th grade—and to increase and improve the opportunities for all people to explore science, mathematics, and technology beyond the school setting. Our goal for Foundations is to embed lessons of reform, not in the language of research, but in the language of real people in real places. We expect future issues of Foundations will address each of the major goals for our Division:

- Develop and implement high-quality instructional materials;
- Provide stimulating environments outside of school that increase the appreciation and understanding of science, mathematics, and technology and their applications;
- Recognize excellence among teachers and students and enhance the status and visibility of the teaching profession;
- Promote interest in and pursuit of scientific and technical fields;
- Provide research experiences in science and mathematics for teachers and students; and
- Create networks of talented teachers and students who can serve as resources for others nationwide.

We believe this issue to be apropos of an inaugural issue—it focuses on many aspects of engaging a system of education (such as a district or other entity) through a concept so basic to the reform agenda—inquiry-based learning.

Finally, thanks to the efforts of CUSER, the Center for Urban Science Education Reform, many leaders engaged in reform have shared their experiences with the intent of supporting your efforts to improve science education.

Margaret B. Cozzens

Margaret B. Cozzens
Division Director

ACKNOWLEDGMENTS

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This issue of FOUNDATIONS is the product of a long-term collaboration between the Center for Urban Science Education Reform (CUSER)—a branch of the Center for Science Education at the Education Development Center, Inc., of Newton, Massachusetts—and the National Science Foundation (NSF). CUSER provides opportunities for a group of school systems engaged in science education reform to improve their programs by learning from each other.

Jeanne Rose Century, Karen Worth, Barbara Brauner Berns, Michele Brusch, Joe Flynn, Judith Opert Sandler, Erica Fields, Doris Santamaria, and Sarah Davis, all from Center for Science Education, collaborated in writing the various chapters of this issue with editorial assistance provided by Ed Miller. The authors worked in cooperation with Susan Snyder, Section Head, Grades K-8 Education, NSF, in designing the purpose, outline, and content of the issue.

For more information about elementary and secondary education, please contact:

Division of Elementary, Secondary, and Informal Education
4201 Wilson Boulevard
Room 885
Arlington, VA 22230
(703) 306-1620

gmcgrude@nsf.gov
http://www.ehr.nsf.gov/EHR/ESIE/index.html

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PREFACE

This monograph is for teachers and district administrators who want to create inquiry-based science programs in their schools. It is but a cursory introduction to the complex challenges of science education reform told through the experiences of others. In the pages that follow, practitioners and policymakers seasoned in reform share their thoughts with the hope of supporting those about to embark on similar journeys. By focusing on the actual experiences of real people in real places, this volume attempts to bring life to the abstract language of reform.

CHAPTER 1 sets the groundwork for the concept of "systemic" change that undergirds the volume thereafter—that is, teaching and learning are part of a complex, interactive system previously misrepresented or underestimated by simplistic and disjointed reform models of the past. The chapter sheds light on why reform efforts that focused on just one or a few components of the system (e.g., curriculum, assessment, professional development) did not succeed or could not be sustained. In spite of the cynicism generated by these past failures, the chapter presents an optimistic, but practical vision of science education reform.

CHAPTER 2 examines what effective science education looks like in real classrooms and describes with concrete examples the practices that do and do not reflect high-quality inquiry-based teaching. It lays out the general direction of current reform efforts: moving from a focus on textbooks and disconnected facts toward direct and coherent exploration of science concepts through active student learning.

CHAPTERS 3 through 8 discuss some of the major elements of change in the system and process of education: planning, leadership, curriculum and assessment, professional development, financing, and collaborations. These chapters explore aspects of reform that are most important for educators who are just beginning a reform process. They are designed only as starting points. CHAPTER 9 focuses on the issue of equity, which infuses each of the other topics in this monograph. It raises a number of difficult questions that practitioners continue to struggle with today in every community across this nation.

Each chapter highlights communities that are actively engaged in science education reform. Contact information is provided for the reader who wishes to know more. Most chapters include a set of references and suggested readings including guides for understanding inquiry-based science education, innovations in classroom practice and professional development, and criteria for selecting instructional materials.

CHAPTER 10, the postscript, poses topics in need of more thought and experimentation. Issues such as effective use of technology, strengthening teacher preparation programs, and methods for evaluating the success of these reforms present interesting challenges for even the most experienced educators.

For the reader contemplating a program of reform, we hope that this document will provide a concrete foundation. But, even for those that have already begun the process, it may ignite ideas that lead in new directions. Ultimately we hope that you, the reader, will go beyond that which is written here—to rewrite these pages with new and better answers to these challenges and the many more that await all of us.

CHAPTER 1

The Challenge and Promise of K-8 Science Reform

New York Times Magazine reporter Sara Mosle captured the current of national debate about school reform in her October 27, 1996, cover story on teaching third graders why things float. Mosle told of her experience teaching science to students in a poor New York City neighborhood school. Describing what sounded like a chaotic classroom "experiment," students were supposed to construct boats from clay, aluminum foil, or paper and test their buoyancy in plastic tubs of water.

This, according to Mosle, was an example of "hands-on inquiry" science. The philosophy behind the approach was "sound enough," Mosle noted. "Kids would act like real scientists, collect and interpret data, learn the laws of nature through observation and then write up reports about what they had discovered. But the theory, as is often the case, foundered on the hard rocks of practice."

Working with 32 unruly students and no aide, water sloshed out of the tubs and wet clay and muddy hands got on everything. Most of the other teachers, she later learned, simply demonstrated the experiment in front of the class and could not believe she was actually letting the students do it themselves.

Mosle concluded in her article, "What Really Matters in Education," that what her students really needed was not playtime with wet clay but "exposure to scientific vocabulary" and a tough, comprehensive curriculum that would provide them with a wealth of factual knowledge on a wide range of subjects. Only then could these children—many with limited command of English—begin to compete with their middle-class, suburban counterparts.

"I despaired at the discrepancy between what they [the children of her middle-class friends] and my students knew, and doubted that 'boats' was going to help bridge the gap. I began to yearn for the kind of textbooks that I had once loved as a kid: big, beautiful books that I liked just holding, smoothing down their shiny pages of colorful illustrations and photographs," wrote

Mosle. She went on to argue that the answer to the problem of U.S. public education lies in strict, explicit national standards and a national curriculum, "set in Washington, and monitored in every town and city through testing."

Mosle's argument most likely made a lot of sense to many readers of the *Times Magazine*. They probably associated the boats experiment with other ideas about "child-centered" classrooms in which kids "have fun" and learn to "feel good about themselves." These ideas, often discredited in political discourse and in the public mind, are seen as diametrically opposite to the traditional values of the schools most adults remember attending—where the standards were tough and unambiguous and the answers to questions were either right or wrong and could be found in the back of the textbook.

If changes are to be long lasting, each and every component part of the system must be irreversibly and permanently altered.

But, what most of Mosle's readers probably did not realize was the fundamental irony in her story. Although the *boats* unit was certainly hands-on, it was not an example of inquiry-based science teaching. (See CHAPTER 2 for a more detailed explanation.) Instead, it was an illustration of what happens when an ill-conceived effort at curriculum reform is imposed on underprepared and undersupported teachers working in difficult conditions. Every third-grade teacher in the district was required to teach *boats*. Mosle, like many other well-intentioned teachers, may have lacked critical supports necessary to make inquiry-based science pay off, such as assistance in teaching science content within the process of discovery, organizing a lesson for a large group of students, or teaching children how to collaborate. It is little wonder that her lesson "foundered."

The deeper moral to her story lies in a more subtle sermon on the nature of change: there are too many complex, interconnected problems present for any one, simple solution—like the introduction of a new curriculum—to alter the fundamental dynamics of teaching and learning in the overall education system or even a single classroom for that matter. Unfortunately, her prescription of a national curriculum incorporates the same failing and is, ultimately, a seductive simplification of what is really needed to transform America's public schools.

What is the answer then? Clear standards for science education (and in the other disciplines as well) that give life and meaning to classroom prac-

tice are an important *part* of the answer, but real, sustainable change demands much more:

- A transformation of people's beliefs about science education well-informed by the processes of science and by our evolving understanding of children's ability to learn complex, thought-provoking material;
- The creation in each district and school of a clear vision of effective science teaching and a set of goals that reflects this evolving knowledge;
- High-quality instructional materials that support a coherent presentation of important science concepts—and the resources necessary to make those materials available to every student;
- New kinds of tests that more accurately measure students' deep understanding of ideas, not just their short-term recall of facts;
- A long-term commitment of professional development to a generation of educators capable of turning this vision of teaching and learning into reality;
- A broadening of public understanding and support for effective science education and the development of community partnerships that spur schools, universities, museums, foundations, and corporations to work toward common goals;
- Steadfast support from district administrators and policymakers who recognize the crucial importance of local school-based initiatives;
- Enlightened leadership that understands how all of these factors affect and depend on each other; and
- All of these changes happening at the same time.

This is the soul of a systemic approach to science education reform: a wide-angle view of school change that sees all aspects of the system as a whole. It recognizes that if changes are to be long lasting, each and every component part of the system must be irreversibly and permanently altered.

We know this to be true in part because of the work of many scholars and researchers and from past experiences with science education reform. Susan Fuhrman and Diane Massell of the Consortium for Policy Research in Education describe how promising reforms falter for lack of "coherence"—that is, an integrated, comprehensive approach to change in which all of the components are organized around a clear set of desired outcomes and a

common vision. David Tyack and William Tobin of Stanford University have written about the ways that innovations in teaching are often selectively implemented and ultimately trivialized. Reformers who wish to avoid this fate, they argue, must reach beyond the schools themselves "to involve the public in a broad commitment to change."

Earlier reform efforts reflected their contemporary currents of educational policymaking and politics. In the 1960s and 1970s they focused on equity and the reallocation of funds to schools in low-income communities. In the 1980s they focused first on *excellence* and later on the demands of teachers for increased authority and control over classroom practice. Although these efforts produced individual success stories in isolated schools and communities, the overall impact was negligible on the large majority of schools and school systems.

Because the concept of systemic reform is complex and abstract, educators and scholars find it hard to portray it in terms that resonate with average citizens.

Educators today face public demands for action that are even more urgent than the warnings of the famous 1983 report "A Nation at Risk." Evidence of student achievement in mathematics and science suggests that the gaps between the *haves* and the *have-nots* remain—especially when one compares white students with students of color. Changes in the U.S. and world economies have made better quality science education a requisite for students at all levels of society if they are to have a chance of prospering in the work force. Isolated successes in education reform are not enough to sustain progress. Changes must take root in every community and must reach the great majority of students.

One of the most daunting obstacles to change is the widespread cynicism among teachers about almost any new school reform effort. Robert Hampel of the University of Delaware has described how teachers typically break into factions whenever schools face deep, systemwide change. The *vanguard* teachers—those most committed to change—never make up more than 25 percent of the faculty, he reports, and often end up pitted against the cynics, those most outspoken in their skepticism. The resulting divisiveness and bad feelings can easily sink the most promising reform effort.

Educators who want to promote effective and lasting improvements need to recognize that there are legitimate reasons for some of this cynicism.

Many teachers have seen waves of reform come and go over the years and have poured their energies into those efforts, only to see them washed away by the next wave. In this sense, skepticism about reform is not simply a matter of stubbornness, insecurity, or laziness—it is a sign of an under-the-surface yearning for changes that are meaningful, not ephemeral. The enlightened leader will find ways to harness the energy of skeptics—by demonstrating, for example, their own steadfast commitment to change even in the face of severe setbacks and disappointments.

Systemic reform of science education is not easy, but there are real reasons for optimism at this juncture. Though there are no guarantees of success, we now have a more realistic picture of the dynamics of change than we have ever had before. Knowing how hard the work will be is in itself an advantage; it thwarts unrealistic expectations. We have some encouraging evidence from the field, as the following chapters of this volume will show. No one has as yet put all the pieces together, but a picture is taking shape that is captured by the many school districts that have made significant progress.

Because the concept of systemic reform is complex and abstract, educators and scholars find it hard to portray it in terms that resonate with average citizens. The phrase *systemic reform* itself, is now widely overused and in danger of becoming a cliché, hollow in meaning. Sara Mosle's *New York Times Magazine* article is evidence of how words like *hands-on* and *inquiry*, which represent important positive concepts to science educators, can easily be associated with poor teaching and misguided ideas in the public mind. Once these perceptions are imprinted in the minds of parents and opinion-leaders, it becomes difficult to undo them.

Widespread support for quality science education hinges on creating a more informative dialogue between educators, researchers, and the public. Educators especially must avoid formulaic jargon and use more direct, clear language in making the case for science education reform. All sides must be willing to engage in a full and open debate about what works and what does not work in school reform.

CHAPTER 2

A Vision of Effective Science Education

"Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning and conducting investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results," states the National Science Education Standards published in 1996 by the National Academy of Science.

Inquiry, this simple three-syllable word requires a paragraph to explain and a vision to make real. Indeed, the phrase "inquiry-based science education" appears everywhere in the language educators use to redefine the teaching of science. The older approach to science teaching emphasized the end point of scientific investigations embodied in facts and truths of the textbook. Students memorized vocabulary, facts, and formulae. They viewed demonstrations and repeated canned exercises, calling them "laboratory experiments."

Instead, *inquiry teaching* leads students to build their understanding of fundamental scientific ideas through direct experience with materials, by consulting books, other resources, and experts, and through argument and debate among themselves. All this takes place under the leadership of the classroom teacher.

This process of inquiry is modeled on the scientist's method of discovery. It views science as a constructed set of theories and ideas based on the physical world, rather than as a collection of irrefutable, disconnected facts. It focuses on asking questions, considering alternative explanations, and weighing evidence. It includes high expectations for students to acquire factual knowledge, but it expects more from them than the mere storage and retrieval of information.

The Challenge

Inquiry-based teaching is a challenge. Contrary to the claims of some critics, it is not a relinquishing of the teacher's role, nor is it simply *messing about* with materials. It is highly structured teaching—but structured to allow students to behave in a most fundamental human way, to be inquisitive. It requires a teacher who is knowledgeable about scientific content and pedagogy, significant blocks of dedicated classroom time, a system that supports the teacher's own learning, and high-quality materials and curricula. In schools where attempts to implement inquiry-based science education have failed, it is often because one or more of these essential elements are missing. In these instances, the rhetoric and superficial trappings of reform can take the place of real change.

Hands-on science is not necessarily good science, as evidenced in Mrs. Glassboro's[1] elementary school classroom:

> Today and for the next several weeks, the children will be studying organisms and their needs. The topic this week is worms. The children have read a book about worms and they are writing stories about their feelings for worms to go with the pictures they have drawn of worms in the school yard. On Friday, Mrs. Glassboro brings in a few worms. The children sit in a circle on the floor, watch the worms, and discuss what they look like and what they are doing. They pass the worms around for all to touch. At the end of the day the worms go back outdoors and the study of worms is complete.

Although one might claim that this teacher is using hands-on methods, many of the important characteristics of inquiry and effective science teaching are absent, rendering the exercise nearly meaningless for the children. The teacher offers the students direct experience with worms only as the capstone of the exercise. No unifying science concepts about living organisms guide the teaching or learning, nor are any generalizations postulated or tested—only topics relating to the specific characteristics of the earthworm are discussed. There is little opportunity for students to formulate and ask questions, to help shape their own learning, or to debate their ideas with each other. Rather than building an understanding of basic concepts about

[1] The names used for the three teachers in this section—Mrs. Glassboro, Mr. Johnson, and Ms. Hernandez—are fictitious, made up only for the purpose of illustration.

living things, they finish their science unit simply having learned a few facts about worms.

In Mr. Johnson's class, the hands-on unit with worms can also be improved:

> After recess, the students express an interest in worms they found in the playground. Mr. Johnson provides a box and some soil for the worms in a corner of the room. When the children have activity time they are free to investigate the worms. Some of them pull worms from the box and look at them with a magnifying glass, others try to make them race, still others try to feed them bits of food. The teacher places books about worms nearby. Over the 3 weeks that the worms are in the classroom, Mr. Johnson periodically asks the children to report what they have seen or done with the worms, which he charts on an easel for all to see. Twice he asks that the worms be the subject of his students' daily journals. At the end of 3 weeks, the children release the creatures in the playground, concluding the unit on earthworms.

Again, too few of the critical components of effective science teaching are present in Mr. Johnson's classroom to consider this a successful inquiry-based learning experience. While the students had an opportunity to explore and investigate the worms—3 weeks is a sufficient block of time—the teacher provided almost no guidance, had no clear set of conceptual goals, and had no coherent plan to make the hands-on unit work.

As is clear from the tale of Mr. Johnson's class, not all student questions, observations, and investigations result in worthwhile learning pursuits. It is up to the teacher to provide structure to the students' inquiry and to support their exploration of only those questions that will yield valuable insights into the scientific concepts under discussion.

In yet another classroom, Ms. Hernandez' second-graders have been working on an interdisciplinary thematic unit on world environments and endangered species. However, sometimes themes can obscure the underlying scientific concepts.

> After reading a chapter in the textbook, the children were put in groups of four and asked to choose a specific environment to illustrate. Six large paintings now adorn the windows, labeled "tundra," "plains," "woodland," "desert," "rain forest," and "alpine." During the second week of the unit, the teacher selected a few activities on habitats so

the students could discuss the concept of completeness and examine their local environment.

Later, the class turned to endangered species. Each group selected a species as the subject of a research project; the resulting mini-reports and diagrams are posted on the classroom bulletin board. As a finale, the students are making their classroom into a rain forest. A tape plays rain forest noises. Books are strewn about. One group of students cuts large tropical trees out of butcher paper. Another makes long, hanging vines. A third paints life-size, parrot-like birds a brilliant red. The work is done. The children are ready to invite their parents and schoolmates to visit the rain forest.

Ms. Hernandez' classroom exhibits some components of inquiry-based science, but the emphasis and focus are not appropriate for the developmental age of the children. Students of this age find it difficult to deeply understand themes of endangered species and world environments. The intellectual scale of the effort is immense; the global distances tremendous. Likewise, there are countless scientific lessons crammed in among the vines, plants, and animals without a critical focus on a tightly knit set of basic ideas.

Although built on hands-on activities, there is no process of inquiry forming the lesson's base. The children have not had the opportunity to investigate these ideas through direct experience. Their learning stems only from secondary sources. The time spent doing scientific investigations and developing an understanding of habitats and their relationships to organisms—both critical to understanding extinction—is small compared to the time spent reproducing words, pictures, and diagrams from library and other materials. Moreover, although connected in a broad sense, the activities do not interlock in ways that permit the understanding of larger, more profound scientific principles.

The Promise

What does an effective inquiry-based science class look like? Ms. Strom uses a well-designed curriculum guide to teach a unit on habitats. Ms. Hudicourt-Barnes leads her students down the path of a lengthy and fruitful investigation by asking a good question about drinking water. Both examples demonstrate what inquiry-based science education can and should be.[2]

Ms. Strom's goal for the unit on habitats is to reinforce her third graders' growing knowledge of the basic needs of living things while

developing in the students a basic understanding of the relationship between an organism and its habitat. As an initial part of the 6-week unit, students investigated habitats around the school, focusing their attention on a few organisms.

By the fourth week of the unit, they have reviewed the basic needs of living things and have, by beginning with themselves and their own needs, explored the idea of complete and incomplete habitats. Then, in small groups, they looked closely at the needs and habitats of living organisms found within 2-foot-square plots in the area around the school. Through small- and large-group discussions, the recording of observations and data in their science notebooks, trips to the media center for reference books and other resources, and consultations with scientists over the Internet, the children's ideas began to crystallize. They began seeing how organisms are adapted to conditions in their habitat and how those habitats provide the organism with the resources necessary to meet its basic needs.

On this particular day, Ms. Strom begins a component of the unit in which the students will build small terraria to temporarily house insects they have seen outdoors. The terraria will allow the students to study more closely how organisms are adapted to habitats. She begins with a discussion of the project and guides the students into thinking about a number of issues as they plan to construct the temporary homes. As Ms. Strom reviews with the students what they have learned, she is also assessing her students' readiness to pull together the knowledge gained over the past few weeks.

The students then divide into their groups to decide which creatures they will collect and to plan terraria to meet the creatures' needs. Toward the end of class, the groups present their ideas and terrarium designs to each other for class discussion and critique. Ms. Strom takes an active role in this discussion, raising critical questions. Several of the groups revise and refine their plans. Later, they gather the materials and capture the creatures. Over the next four classes the students

2 Portions of this section have been taken, with permission, verbatim from a report titled "Cheche Konnen: Scientific Sense-making in Bilingual Education" in *Hands On* (Spring 1992, Vol. 15, No. 1), a newsletter produced by TERC, an organization that works to improve education. The report was written by Ann Rosebery, Beth Warren, Faith Conant, and Josiane Hudicourt-Barnes about work done under the auspices of the Cheche-Konnen project by Ms. Hudicourt-Barnes' Haitian-Creole bilingual classroom at the Graham and Parks Alternative Public School in Cambridge, MA. The other teacher mentioned in this section—Ms. Strom—is fictitious, made up only for the purpose of illustration.

will observe their creatures closely, both within their temporary homes and in small bug boxes. At the conclusion of the exercise the student teams will present what they have learned, the class will discuss their findings, Ms. Strom will bring conceptual closure to the project, and the creatures will then be released into their natural habitats.

Ms. Strom's classroom demonstrates important characteristics of inquiry-based science teaching. Using a written guide from an established curriculum, she carefully follows the story line so that her students' understanding of the underlying biological concepts builds logically in both scope and sequence. The students' inquiry is supported through secondary sources such as electronic media. Their investigations begin by making connections to their own environment.

She is careful to allow time for the students to make entries in their notebooks and to discuss their work in both small and large groups. This, together with her constant informal interventions with students, allows her to continuously assess the children's state of knowledge and to alter her pacing of the unit accordingly.

Ms. Strom's third-grade class has been able to make logical conclusions about habitats based on their own direct experience in this tightly designed unit. For Ms. Hudicourt-Barnes' older students, inquiry takes on more advanced features, a more open direction, and proves itself to be a matter of taste.

Ms. Hudicourt-Barnes, teacher of a combined seventh- and eighth-grade bilingual class of Haitian youngsters, watched as her students streamed in from gym class one February day only to race off to a far-away third-floor water fountain. She wondered why no one stopped to drink from the much closer, first-floor fountain. After observing the same behavior several times, she asked a few of the students why. All instantly replied that the water was "better" on the third floor. Ms. Hudicourt-Barnes challenged them to prove that this belief, apparently shared by most of the seventh and eighth grade, was really true; and if true, to explain why.

The students set out to determine if they really preferred the third-floor water by designing a blind taste test of water samples from the first-, second-, and third-floor fountains. They found that two-thirds of them chose the water from the first floor in the blind test, although every one of them had previously claimed to prefer the third-floor's water.

The students did not believe their results. Further discussion revealed that the kids firmly believed that the first-floor fountain was the worst because "all the little kids slobber in it." (The first-floor fountain is near the kindergarten and first-grade classrooms.) Ms. Hudicourt-Barnes was also suspicious of the test results, because she had expected no differences among the three fountains. These suspicions motivated the class to conduct a second taste test with a larger sample of tasters drawn from the other seventh- and eighth-grade classes.

The students decided where, when, and how to run the experiment. They discussed methodological issues: how to collect the water, how to hide the identity of the sources, and, crucially, how many fountains to include in the test. They decided to draw from the same three fountains as before, so they could compare results of the two rounds of tests. They worried about bias in the voting process: what if some students voted more than once? Each student took responsibility for a piece of the experiment. About 40 students from other classes participated. When the data were analyzed, the results were similar to the earlier test: 88 percent of the students thought they preferred water from the third floor, but in the test, 55 percent actually chose the water from the first floor.

Faced with this evidence, the students' suspicion turned to curiosity. Why was the water from the first-floor fountain preferred? How could they determine the cause of the preference? Earlier in the year the class had completed a unit on water and the water cycle. In conjunction with the unit they had worked with the local water resources agency and studied where their water came from and how it was cleaned and monitored. They had the tools and understanding to apply to this new problem, and decided to analyze the school's water along several dimensions, including acidity, salinity, temperature, and bacteria levels.

They found that all the fountains had unacceptably high levels of bacteria. In fact, the popular third-floor fountain had the highest bacteria count of the lot. They also found that the water on the first floor was 20 degrees cooler than the water on the other floors. Based on these findings, they concluded that temperature was probably a deciding factor in the blind taste-test results. They theorized that the water was cooled naturally as it sat in the city's underground pipes and warmed as it flowed from the basement to the third floor.

Ms. Hudicourt-Barnes was delighted with what had come from the initial taste-test idea. Her students had eagerly used computers to analyze their data and write their reports. She was also pleased by the level and quality of interaction between her bilingual class and the monolingual classes.

Ms. Hudicourt-Barnes has a year-long planned science curriculum, including the study of water. But her plan is flexible enough to allow students to pursue an unplanned inquiry in considerable depth. Her classroom offers the materials and tools needed for investigations. She is willing to share responsibility for learning with her students, thereby encouraging

CHANGING EMPHASES

The *National Science Education Standards* envision change throughout the system. The teaching standards encompass the following changes in emphases:

Less Emphasis On	More Emphasis On
Treating all students alike and responding to the group as a whole	Understanding and responding to individual student's interests, strengths, experiences, and needs
Rigidly following curriculum	Selecting and adapting curriculum
Focusing on student acquisition of information	Focusing on student understanding and use of scientific knowledge, ideas, and inquiry processes
Presenting scientific knowledge through lecture, text, and demonstration	Guiding students in active and extended scientific inquiry
Asking for recitation of acquired knowledge	Providing opportunities for scientific discussion and debate among students
Testing students for factual information at the end of the unit or chapter	Continuously assessing student understanding
Maintaining responsibility and authority	Sharing responsibility for learning with students
Supporting competition	Supporting a classroom community with cooperation, shared responsibility, and respect
Working alone	Working with other teachers to enhance the science program

National Research Council. (1996). *National Science Education Standards*. Washington, DC: National Academy Press.

thought and reflection, but she also questions and challenges their work and demands evidence and argument to support their assertions.

The Debate Continues

A vigorous debate is currently under way about the most effective ways to teach science. Two critical areas in this debate are the importance of content versus process and the nature of effective instruction. E. D. Hirsch, author of *The Schools We Need*, argues that content has taken a back seat to process in progressive education, and that so-called direct instruction is preferable to inquiry-based teaching. In an issue of the *American Educator* he attacks constructivist reforms and cites research to demonstrate the superiority of direct instruction and the acquisition of factual knowledge.

The current inquiry-based science reform effort values depth of understanding of basic concepts, learning the process of scientific inquiry, and students' assuming significant responsibility for their own learning.

"The only general principle that seems to emerge from process-outcome research on pedagogy," writes Hirsch, "is that focused and guided instruction is far more effective than naturalistic, discovery, learn at your own pace instruction." He argues the need for students to learn substantial content and not simply the process of science and how to learn. "The conclusion from cognitive research," he states, "shows that there is an unavoidable interdependence between rational and factual knowledge and that teaching a broad range of factual knowledge is essential to effective thinking both within domains and among domains" (Hirsch, 1996).

Hirsch is certainly not wrong, but he and other critics are in danger of setting up a false dichotomy of content versus process. Neither is the answer. Teaching that concentrates solely on one and ignores the other is not helpful to students.

Science teaching embraces a wide range of methods. At one end of the continuum is the classroom in which knowledge is defined by the text and students learn from readings and lectures. Their success depends on understanding the requirements of the teacher and learning terms and formulae. On the other end of the continuum is open exploration of materials with little guidance or structure. Hirsch does not advocate the first extreme; he

admits a place for inquiry in science education and the need for students to take some responsibility for their learning. Responsible reformers also dismiss the extremes in favor of the middle ground, suggesting that the current changes in science teaching involve a shifting of emphasis along this continuum. The National Science Education Standards call for more or less emphasis on certain instructional strategies as they advocate this move down the continuum.

The heart of the disagreement is about where the proper balance should be. Those who see a need for more emphasis on content will give students less time for investigation, debate, and argument than those who value these processes and who aim for deeper understanding of fewer topics. The latter will give more time to small-group work, argument, and debate, and less time to textbooks and library research.

The current inquiry-based science reform effort values depth of understanding of basic concepts, learning the process of scientific inquiry, and students' assuming significant responsibility for their own learning. There is a balance of content and process in inquiry-based science, but teachers who hold these values may differ in their methods. The character of each classroom emerges from the decisions of teachers and from the rich diversity of individual children, communities, and school systems.

It is not enough for reform-minded educators to turn to the standards, to the research, or to a particular curriculum for answers. We see today many examples of good inquiry-based science teaching, but also many examples of "hollow inquiry," practice that is called inquiry but has few of its essential characteristics. Educators must first understand their own values and engage in their own inquiry—to develop a deep understanding of their communities' needs and goals for rich, vital science education.

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CHAPTER 3

Planning for Change

The bridge connecting the vision for reform with all other parts of the system—leadership, curriculum, instruction, assessment, professional development, finance, evaluation, and equity—is the plan for change.

Continuous, thoughtful planning can help launch the vision, keep participants on track, and keep short- and long-term goals in constant view. The process requires planners to reflect on their work and to involve diverse stakeholders. The result is a clear sense of group purpose, shared expectations, and ultimately a higher level of support and *buy-in* for the reform effort.

Valuable plans are the result of a cross-section of people, inside and outside the school system, working together with a common goal.

The most valuable plans for science education reform build upon other strategic planning efforts in the district. The ones most likely to be taken seriously are those that are integrated with other major district efforts. There may be many existing plans or a set of planning efforts taking place simultaneously in a school or district on any number of topics such as desegregation, special education, magnet schools, bilingual education, performance-based accreditation, program quality review, and efforts to improve students' test scores. But, to become a truly successful venture, science education reform planning must become part of the whole, rather than an add-on. The goal is clear: ease the work of educators, do not make it more difficult.

Valuable plans are the result of a cross-section of people, inside and outside the school system, working together with a coamon goal of improving all students' access to high-quality science programs. Planning by a leadership team—involving the district's educators, policymakers, parents,

community representatives, and often university faculty—typically focuses on developing

- a vision;
- goals and objectives for inquiry-based instruction;
- an overall approach and specific steps for district and school implementation;
- a district framework that outlines what students should know;
- a process for evaluating progress toward program and student goals using a range of methods including student outcome data; and
- a realistic timetable.

In places where science reform is progressing, there is usually a comprehensive long-range plan. Unfortunately, there are still too few examples of successes within these long-range reform efforts because many have only recently been launched. But if there is any single lesson to be learned from them, it is that there is no single *right* approach. Effective plans reflect the uniqueness of their communities—their problems and resources. This is not to say that nothing is known about what leads to successful planning. Much has been learned from the experiences of those who have gone before. Their recommendations and cautions should be considered when planning reform.

Planning teams should begin by examining practices, policies, programs, and research that can inform the district's thinking and decisionmaking about science reform.

The best district-wide planning approaches tap the unique expertise of team members and reflect the district's own way of doing things. However, practitioners have identified several activities that are valuable for everyone because they help to determine district needs and the strategies school systems can use to meet initial goals for science education reform. It is usually important to give attention to the national context as well as the state's and district's unique situation, history, current status, and resources available for science education.

To assess the national situation, districts can examine national standards for science as well as the most recent and compelling research on child learning, instructional strategies, and assessment. Planning team members often identify and, if possible, visit districts across the country that are implementing inquiry-based science programs—particularly those districts that have similar student populations or those that have made science a high

priority. In these communities, team members can see how science has been made a core subject, how teachers receive well-designed professional development (see CHAPTER 6), and how sufficient financial support (see CHAPTER 7) has been made available. In addition to looking at other school systems, districts often contact professional associations and other known experts to learn about nationally validated instructional materials that align with science standards, promote problem-solving and critical thinking, and serve as examples of good practice.

Contact with experienced practitioners nationally and statewide is perhaps one of the most critical aspects of planning.

At the state level, planning teams will often review the agenda for science education. The state science framework or objectives and the status of statewide assessments in science for elementary, middle, and high school students are often studied. Options for statewide professional development in science content knowledge and pedagogy and the status of newly evolving teacher certification programs or teacher preparation programs at the local colleges and universities are given attention. Again, team members may identify and visit schools and districts—this time within the state—that are implementing inquiry-based science programs that are aligned with state frameworks.

Equally important is to assess the district's current science program across all schools and grade levels. This may not be as easy as one might initially expect because of the autonomy many schools have in matters of curriculum and instruction. Therefore, planning team members need to be careful in determining how to examine the current condition of science education in the district and how to evaluate its strengths and weaknesses. The identification and input of teacher leaders and strong principals is important at this phase. Likewise, it is critical to assess the actual and perceived needs for change and potential barriers to change. Such assessments can take the form of surveys, questionnaires, peer observations, and examination of student work.

Contact with experienced practitioners nationally and statewide is perhaps one of the most critical aspects of planning. Howard Nadler, science coordinator in New York City's Community School District 5, explains: "It was especially helpful to us to talk to people who were engaged in the

SMART PLANNING IN NEW YORK CITY

With a boost from the National Science Foundation, planning has begun to pay off for New York City Community School Districts 3 and 5. The districts have been reorganizing all of their elementary schools to reflect the teaching and learning model of what they call the "SMART Process." But, the planning really started even earlier with a vision. Explains Howard Nadler, co-project director, "prior to getting the planning grant both districts had decided inquiry-based instruction was what we wanted to do, with whatever resources we had."

"In each school we developed school-based literacy teams. From the beginning we were trying to say science was a vehicle for overall literacy." Nadler and the other project director, Howard Berger, are now working to link the science and mathematics reform with other district goals. "We've tried to formalize that process this year with two three-day institutes called Science Links to Literacy,"adds Nadler.

The co-leaders and their colleagues developed a check list for their SMART planning process:

- Identify and bring stakeholders (internal and external) together into a planning team.
- Look for funding sources (e.g., planning grants), if district resources are limited, that will support a comprehensive planning process.
- Conduct an assessment of best science education practices, programs, and policies.
- Based on the results of the assessment, create a shared vision, establish goals, and plan specific steps to reach the vision and goals.
- Identify funding sources to initiate and sustain systemic science reform.
- Establish a plan for communicating goals with parents and the community at large.
- Build partnerships with business, higher education, and other community organizations.

Nadler and Berger used their initial seed money to support a year of planning that included a self-study and making visits to several districts already engaged in systemic reform. Then, the two districts submitted a proposal for an NSF Local Systemic Change Through Teacher Enhancement project and were funded to initiate their reform. "It's not been easy," but Nadler remains optimistic. "If we can make it in New York...we'll make it anywhere!"

process. Reading is helpful, but it was more useful to sit down and talk with someone and ask the hard questions. We visited sites of current NSF projects so we could pick their brains about the lessons learned—and some that were not learned."

The plan should be realistic, with concrete steps and clear descriptions of individual and institutional responsibilities and commitments.

A useful plan is more than just a broad statement of vision. It also spells out where the project is going in specific terms, who is going to do what when, and how they are going to get the support they need to accomplish stated goals. The plan must include mechanisms for tracking progress toward the specific goals and evaluating the success of the program over time.

In some districts, progress has been slowed because plans were vague, lacked clear commitments, or the assignment of responsibility was too diffuse. In one district, for example, the program implemented leadership development, staff development, curriculum restructuring, partnership alignments, and other components of its plan. But financial setbacks and other problems in the district delayed the distribution of materials for several years. Many teachers who were eager to implement new practices were not able to do so. Clearer commitments and responsibilities regarding alignment of financing materials and professional development could have helped prevent this loss of momentum.

Other districts have had difficulties because their plans were incomplete. Effective plans address many different areas including, but not limited to,

- time devoted to science instruction for all students;
- school and district-based support for science;
- curriculum materials;
- instructional models;
- assessment approaches;
- materials management;
- support for teachers' knowledge of science content; and
- the assessment of student learning outcomes.

Within each of these areas, there are often multiple tasks. In planning professional development, for example, team leaders need to include more than pedagogy. They also must include leadership development, assistance with science content, and an understanding of how students learn science. As one district leader commented, "It needs to all happen at once and that makes it difficult."

Such planning can be time consuming. "Time for thinking and planning is the biggest barrier," says Linda Gregg, administrative specialist for K-5 mathematics and science in Las Vegas. And yet the benefits that result from time well invested are enormous. Participants gain a deeper understanding of the reform, become more committed to taking action, and develop the trust and relationships essential to sustaining and furthering change.

The plan should be a "living" document that evolves with changing conditions in the community.

Plans must be flexible and planning processes continuous in order to take advantage of the changes that are sure to result from the reform program itself. As a reform takes hold, new needs arise. For example, professional development must advance along with teachers' growing expertise. Budgets, too, have to accommodate change over time. Gil Turchin, special assistant to the superintendent in New York City Community School District 3 notes, "As we scale up our commitment to more schools, we have to pay teacher-facilitators, buy kits for each classroom, buy libraries related to each science. We expect to increase our financial commitment by 25 percent a year." Linda Gregg in Las Vegas adds, "Our project is multidimensional and we're just learning how to define that—going from small group planning to broad group planning and back to the small group. Back and forth. It never stops."

Science educators need to do a better job of engaging community support by giving the public an accurate portrayal of the goals of reform.

Districts are in constant change. Superintendents come and go. Community demographics change. This may require revisiting the leadership roles assigned in the plan or it may mean reexamining the treatment of topics within the plan. Although unanticipated change will surely come, the plan can lend greater stability to districts in times of change than if no plan had existed. Moreover, the plan itself can act as an impetus for discussion, delineating changed responsibilities and evaluating progress of the program. When new voices come along, plans help in getting the buy-in necessary for sustaining reform. "I don't think we've ever felt like we were done. We are constantly modifying what we're doing based on the feedback [of those joining the process]," explains Sam Alessi, associate superintendent for curriculum, development, and evaluation in Buffalo.

PLANNING UNIFIES SAN FRANCISCO

When the University of California, San Francisco (UCSF) received a teacher enhancement grant from the National Science Foundation to train 100 new teachers in kit-based science-inquiry instruction, there were already two ongoing science education reform projects in the San Francisco district. The two earlier projects—one funded by the San Francisco Education Fund and the U.S. Department of Education to develop a district-wide group of teacher leaders, the other, an Exploratorium project previously supported by NSF to provide individual teachers with deeper knowledge of inquiry-based teaching—had similar and complementary goals.

Despite this, there had been no real coordination among the different initiatives: but after a series of meetings between the three groups, positive results began to emerge. "Once the focus shifted away from the programs and onto the needs of the kids, people were able to leave their egos behind," says Annabelle Shrieve, formerly the director of the UCSF project and now at Education Development Center, about how their work fit together. "It was just a lot of give and take," notes Shrieve, "each project had something to offer an integrated plan." The Exploratorium had the resources of a big museum; the university had scientists, labs, and an affiliated hospital; the San Francisco Education Fund had teachers with more highly developed scientific backgrounds.

Basic trust first had to be established among the three groups as they struggled to get past some obstacles. But today, the three projects are no longer distinct. They have integrated into one unified plan to support elementary science education reform in the entire City of San Francisco.

There should be one unified plan that integrates all science activities in a school or district. This plan should be consistent with, or integrated with, plans for other subject areas and the school's or district's overall plan for reform.

Most successful districts avoid the *project mentality*, seeing reform as a collection of projects, and, instead, focus on systemic reform as a *big picture*, a unified, inclusive view of science within the context of the school district's more far-reaching goals and objectives, policies, and programs.

The plan for science must itself be comprehensive and coherent, and must in turn be consistent with broader district goals. Some schools, for example, are *science rich*. They have science fairs, museum programs, field trips, science enrichment programs, professional science consultants, and a menu of workshops for teachers. Though numerous, these activities are often just activities—fragmented and independent, building deep understanding of science in neither teachers nor students. Instead, schools and districts

need a unified plan that aligns everything to the core curriculum and the broader goals of the program.

In places where site-based planning and decisionmaking are high priorities, curriculum, professional development, and assessment may vary from school to school. In many of these districts, in fact, there are two parallel plans—a district plan and a site-based plan. Though this has the advantage of promoting local ownership of the reform effort, it can create problems for planning, implementation, and program evaluation. It is up to district and site-based educators to figure out how to connect each school's priorities with district expectations for implementation and student outcomes while making sure to meet mandates in the district's required plans for such programs as Title 1, special education, and bilingual education.

The process of creating a unified plan is sometimes frustrating and arduous, but, if nothing else, it helps to illuminate the compatibility and tensions that exist between pieces of the plan and the district's larger goals.

The plan should be defensible to those likely to question it.

Parents, the public at large, and other educators are often skeptical or distrustful of arguments for inquiry-based science instruction. Some may object to using textbooks as resources instead of as the drivers of instruction, or classrooms where children are moving about talking to each other. Active classrooms often involve a kind of *planned chaos*, but to parents it may seem like chaos nonetheless. Some parents may want their children to learn science in the old way—the way they were taught. Or they may want their children to use textbooks, knowing that college courses are often organized this way.

Somewhere, somehow, or at sometime, the case for science reform will have to be made and a defensible plan will become a necessity. Linda Gregg argues that science educators need to do a better job of engaging community support by giving the public an accurate portrayal of the goals of reform. Her efforts in Las Vegas encountered opposition from those who favored a *back-to-basics* approach to teaching.

A strategic approach to planning helped Gregg. "Discussion is not a bad thing," she says. "It has sharpened our vocabulary and identified 'red flag' words. Knowing your contextual community helps. Then you can refine the language you use in describing what you do. We try not to use the word 'reform.' Some people are willing to look at 'practices,' but saying 'reform' implies you're taking a side."

Others make the case for inquiry-based science by suggesting that it is an avenue to more equitable practice. Teaching science this way creates classrooms in which all students, not just a select few, can learn science. Others demonstrate how inquiry-based teaching in science actually empowers children to learn, the benefits of which can carry over to other disciplines (see CHAPTER 9).

Perhaps the most basic aspect of the plan is a clear communication strategy. One approach to improving communication, for example, is to show parents what really takes place in the classroom. At parent meetings, students can set up materials and lead their parents through investigations. Partnerships can be built with museums and other community organizations that will not only increase the credibility of the school's reforms, but will benefit the community's understanding (see CHAPTER 8). Another strategy is to engage university faculty members and scientists as collaborators and spokespeople. Whatever strategy is used, making the case for science education requires project leaders to be savvy. As one seasoned educator pointed out, "It is essential to know the agenda of those in power. If you can gain their support—especially financial support—the public is more likely to come along."

PLANNING RECAP

1. Planning teams should begin by examining practices, policies, programs, and research that can inform the district's thinking and decisionmaking about science reform.
2. The plan should be realistic, with concrete steps and clear descriptions of individual and institutional responsibilities and commitments.
3. The plan should be a "living" document that evolves with changing conditions in the community.
4. There should be one unified plan that integrates all science activities in a school or district. This plan should be consistent with, or integrated with, plans for other subject areas and the school's or district's overall plan for reform.
5. The plan should be defensible to those likely to question it.

Suggested Readings

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CHAPTER 4

Leadership

Everyone talks about the importance of leadership for successful systemic change, and there is no doubt that without it, reform in science or any other aspect of education will not happen. Leadership implies change and movement. To lead is to move a group in a specified direction. Without leadership there is no purposeful change. Without change there is no *re-forming*.

Yet there is enormous confusion about what leadership really is. Many people assume that leadership is what leaders do, and that educational leaders are, naturally, the people in positions of authority—primarily district and school administrators and supervisors. Much research into the process of educational change—as well as the experience and testimony of teachers—tells us that this is an overly narrow, disempowering viewpoint. One need only look as far as the nearest top-down reform effort. These, based solely on directives from administrators, simply do not work very often.

Those who believe that leadership means the communication of a mission from the *leader* to school personnel are omitting a crucial element of organizational dynamics. Real leadership can be exercised by people at all levels of an organization, whether or not they hold formal authority for making policy or day-to-day decisions.

For schools, this means that the superintendent, assistant superintendent, science coordinator, principals, teachers, parents, students, and other members of the community can all exercise leadership, with varying levels of authority and responsibility. Indeed, systemic school reform is so complex and so difficult that real progress often depends on having as many people as possible take responsibility for making it happen.

This is not easy. In many districts where decisions have typically been made centrally, for example, there is talk of "flattening the organization" and "empowering teachers." Many teachers are skeptical of such talk, having lived through earlier periods of "shared leadership" that often left them with the responsibility but little of the authority or power. Those engaged in

change should systematically consider the relationship between responsibility, authority, power, and leadership; and how to engage the whole community of leaders in that process.

Leadership in the systemic reform model is the sharing of authority and power so that others gain a meaningful degree of control over their own work. Leadership also means being able to reflect honestly and critically on one's own practices and being willing to reconsider and perhaps change some deeply held beliefs. In this chapter, practitioners who have been actively engaged in systemic science education reform offer some lessons that emerged from their experience with leadership.

Exercising leadership requires decision-making power or direct access to decisionmakers.

Leaders of science reform efforts must understand how the system works and know how to interact with people at all levels (U.S. Department of Education, 1996). This means figuring out what systems are in place, how those systems are structured, and where the science reform initiative fits in. The next steps are identifying what has to be modified, and how that might happen. Negotiating this kind of authority can be tricky, but it is essential.

Leadership in the systemic reform model is the sharing of authority and power so that others gain a meaningful degree of control over their own work.

One science coordinator reports that in his community, no reform effort has credibility unless the superintendent personally endorses it and reiterates support on a regular basis. The challenge facing the science coordinator, however, was finding a way to develop the widespread, grassroots support in the program necessary to ensure its sustainability. That kind of leadership could not come from a superintendent's mandate.

Another coordinator had the opposite problem. She had successfully developed support for the program from teachers and school administrators across the district. Her frustration came from the fact that the people above her lacked deep understanding of the reform, a prerequisite of vision that is necessary to drive the right decisions. Decisions were ultimately made anyway, this time based on political reasons, which led to negative impacts on the program and serious ripple effects. Her leadership challenge was to find

a way to persuade the people in authority to make the right decisions.

"Without some measure of autonomy, some ability to make decisions on behalf of their colleagues...teacher leaders cannot create effective positions," writes Pat Wasley (1991). In some cases, access to decision-making power is accomplished by including teacher leaders in the planning of a reform program from the beginning. Annabelle Shrieve, formerly with the San Francisco City Science project, points out, "it shouldn't be the central office deciding that the teacher leaders should do this or that. The teacher leaders should contribute to the discussion about what they will be doing—what they feel comfortable doing." District-level leaders need to listen closely to what those teachers are saying and, at times, "they might have to take a risk," says Shrieve. "That's hard for central office staff."

Those with decision-making power or formal authority are sometimes not effective leaders. "Lots of people who have titles may be exerting management," says Sam Alessi, the associate superintendent in Buffalo, "but they aren't exerting leadership." Paradoxically, teachers who exercise leadership in more informal ways are often more successful. Melva Greene in the Baltimore City Public Schools has noticed two kinds of teachers involved in reform: "The ones who do it themselves, and the ones who are able to influence others to do it." The ones who do it themselves teach science in their own classrooms, have a sense of what is good for children, and provide a grounding or reality check for their colleagues. The others, the informal leaders, step outside their own classrooms and begin to persuade others that inquiry-based science is good for their children.

John Cafarella, director of science in New York City Community School District 6, has found that some of the most effective leaders in his district lead in subtle ways, such as through example. "They have the knowledge, but they don't tell people what to do," he says. "They make the experience come alive for the participants."

School and district personnel who want to exercise leadership are helped by having clearly defined responsibilities, adequate support, and opportunities to do their work.

Most communities beginning a systemic science education reform effort need to identify those who will take responsibility at the outset for planning, communication, and professional development. As an initiative begins, however, there can be a great deal of confusion about these roles. The leaders themselves may not know exactly what kind of support and authority they will have. Often, other teachers and administrators do not clearly understand

MORE THAN BOUTIQUES IN NEW YORK

In offering advice about identifying leaders, John Cafarella, the director of science for New York City Community District 6, says, "don't make the mistakes we made." During the first years of professional development for *point lead teachers*, District 6 offered college credit and enrolled people in the course, but there was no way to hold them to a commitment back in their schools.

Identifying and supporting leaders was successful, but only in isolated ways—they had what Carafella calls, "boutiques of success." In other words, the district was not on a trajectory toward sustained, systemic change. This year, they decided to focus on full-time teacher-leaders they call science facilitators. The facilitators customize their support to each school and focus on building leaders at each site. This approach has proven successful and is increasing confidence that they are headed toward sustained change.

what the leaders are supposed to do. Clear descriptions of these roles are essential (Carter and Powell, 1992).

Clarifying the roles of leaders must go beyond putting pen to paper. In one community, for example, the expectations for school-level teacher-leaders were not clearly defined; there was widespread confusion about what they were supposed to do. One teacher thought her role was limited to "sharing information about the science program with other teachers in the school." Another thought she was expected to provide professional development for her colleagues. Others focused mainly on providing materials to colleagues or on doing demonstration lessons. The science coordinator learned about the confusion from the project evaluator and responded by writing descriptions of the leadership expectations for the teacher-leaders and administrators. But without real models or direct experience, this document had neither the authority nor the credibility the teachers and principals needed to translate the role descriptions into real classroom practice. "If you've never seen or sensed it, it's hard for you to know what to do. Somewhere along the line you hope that someone has modeled for you what leadership is," explains Bill Badders, a science resource teacher in Cleveland.

Badders has found that teacher-leaders need continuing, meaningful professional development—a subject also familiar to Sam Alessi, who believes that it is just as important for teachers "to share what has been working and not working, and to reflect on and discuss their own leadership," as it is to provide them with opportunities for professional development in inquiry-based science. In Las Vegas, teacher-leader Lorraine Blume experiments with "bring alongs"—joining a potential leader with a more experi-

enced leader. The two work collaboratively to plan and facilitate professional development, much like a mentorship, and then meet with others in small study groups to debrief.

Educators have found that professional development for leaders needs to go beyond honing leadership skills. It also must include support for the leaders' own understanding of science content and how children come to learn that content. This is the aspect often overlooked.

Even when teacher-leaders know what to do and have professional development support, they do not necessarily have adequate opportunities to fulfill their roles. This is a cue for administrators to exercise their leadership and to provide support and access. Teacher-leaders cannot be expected to support others when they themselves do not get sufficient support. Initiators of reform cannot ask them to do something with nothing. Teacher-leaders must have sufficient time during the school day to plan and support others, and they must have access to the people they are supposed to be supporting (Powell and Carter, 1992).

Bill Badders credits his principal, Jim Balotta, with enabling him to become a leader in his Cleveland district. "It really was what he did those first years when I worked with him," says Badders. "He tended to let me try things. He found ways to support everybody. Good leaders know the strengths and weaknesses of the people around them and are willing to give up some of their power or control over an issue. They trust others to take the lead, and support them when they are successful and also when there are failures."

NECESSITY IS THE MOTHER OF INNOVATION IN LAS VEGAS

Las Vegas, Nevada, is growing faster than nearly any other school district in the nation. Linda Gregg, supervisor in the office of mathematics and science, faces the challenge of identifying and providing professional development to a constant flow of newly minted teacher-leaders.

Despite the challenges, Gregg has managed to succeed. The NSF-funded Local Systemic Change project, focusing on both mathematics and science, uses a number of innovative strategies. First, there is a site liaison at each school who takes on a range of roles depending on the progress of that school and the liaison's experience. Second, they have released a cadre of teachers on special assignment who provide full-time professional development support and participate in the planning and leadership of the project. Finally, they have developed mentorship strategies to bring new teachers into leadership roles.

Due to the increasing demand, these new teacher-leaders are sometimes given responsibilities before they are completely comfortable, but Gregg is never far behind with support and professional development.

Leadership functions best when it is distributed across several people who work as a team.

Change cannot be imposed, particularly when the scope of the change is a whole system. Researchers have found that it is useful to identify and support a group of individuals in every school in a system in order to seed widespread support for reform (Kober, 1993). Some practitioners seem to have found ways to move beyond creating a few new roles for individuals in a school and have reorganized their schools to "create an open collaborative mode of work to replace teacher isolation" (Lieberman, 1988). The Center for Urban Science Education Reform has found that the most successful schools have incorporated the leadership for the science program into the leadership structures and cultures that were already working in the school.

Collaborative leadership is practical: when individuals leave the system, others are already in place to support the continuation of the initiative.

But, sometimes leadership by committee is not the answer. In these instances, the critical intervention of an individual with authority is essential. At Orchard Elementary in Cleveland, principal Teacola Offett acknowledges that her school's participation in a district-wide science program did not really work until they started to use a team approach. There have been times, however, when the committee "can't agree on what they want to do," she reveals, "usually because they don't know what they are trying to do." At such times, Offett believes, she must step in to focus the group on its purpose. But, she reminds herself, "it takes more than one person to carry out the mission."

Collaborative leadership is also essential at the district level. This does not necessarily mean that all decisions are made democratically or "driven to consensus...nor does it mean that empowerment is something that leaders dole out to employees like scoops of ice cream" (Meunier and Gabor, 1995). Rather, the greatest value is in creating opportunities for open communication, mutual critique, and collaboration. "I don't know that there's any other way to do it," says Sam Alessi. "There is a leadership role that needs to be played at all levels. The more you broaden that cadre, or leadership bank of support, the more successful your initiative will become." Alessi also points out that collaborative leadership is practical: when individuals leave the system, others are already in place to support the continuation of the initiative.

LEADERSHIP IN BALTIMORE IS OFTEN EASIER SAID THAN DONE

Even before the shake of a hand, Andrea Bowden spontaneously cautions, "it's easier said than done." She views her work with Melva Greene in the district's central office as a "continuing saga." Bowden and Greene are the leaders of Baltimore's teacher-leaders.

Bowden continues, "that's one of the [big] issues with systemic reform. It doesn't happen overnight. It's an ongoing effort that takes more resources than you ever thought were going to be necessary and I don't just mean money," she pauses and sighs. "It takes people cooperating and all kinds of policy changes that sometimes fall into place and sometimes don't. Sometimes you take one step forward and two steps back."

Bowden and Greene perceive their role as leaders in many dimensions. They support the other district-wide teacher-leaders, support teacher-leaders who are based in their schools, and provide opportunities for continuing growth for all leaders and classroom teachers.

But when it comes down to it, however, they view their role as setting the vision and mission of the group. Though they are committed to widely sharing leadership and planning, they also have learned that "you have to have a pretty firm vision or you lose a lot of time." So, they work across the district to build the vision and work collaboratively to develop and support it. As Bowden explains, "[you] point people in the right direction, give them the materials to work with, and allow the creativity to craft a plan."

Effective leaders must be credible and have a rapport with and the respect of their colleagues.

All leaders, whether with formal decision-making power or informal authority, need credibility (Carter and Powell, 1992). In Baltimore, Andrea Bowden, supervisor of science, mathematics, and health, and Melva Greene, a curriculum specialist, found that it helped to work with people already recognized as leaders, because usually these people were "successful with children, had faith in children, and were respected by their colleagues." The rapport these teachers enjoyed with colleagues is grounded not in any formal title or authority but rather in their personal qualities and their relationships to others in the school. These personal qualities include empathy, ability to collaborate, knowledge, and having a sense of humor.

Also important, particularly for teacher-leaders, is enthusiasm—simply wanting to do the work. Often this desire is tied to a strong personal connection or stake in the reform. But it also is more than a desire to make change. It is reaching what Bowden calls a "maturation in your own professional life," a point where, "you want to take a step beyond impacting just the children in your own classroom." Nevertheless, a teacher may be the best in the

school with children, but may not work well with adults. The ability to work with children and adults alike is critical for teacher-leaders.

Effective teacher-leaders continually strive to improve their teaching practice, develop their skills in inquiry-based instruction, and sharpen their understanding of science content. A mark of their success is their willingness to continue to see themselves as learners. In Las Vegas, Linda Gregg looks for people who are open to new ideas, think deeply about how children learn, are flexible in their thinking, and are willing to reflect on their own practice. She wants people who are "continuing learners and willing to change."

Sam Alessi of Buffalo has found that, "you tend to assume that the kinds of changes that you are trying to implement are happening and this isn't always true. In fact, it often isn't true. It's difficult for those of us in leadership roles to accept that we have to question our assumptions." As a result, Alessi values people who are willing to participate in evaluation, but he does not exclude himself from the process. Says Alessi, "We are constantly modifying, expanding, and changing what we're doing based on the feedback and input from everybody involved." It is the only way to get to the bottom line, "making a difference for kids."

Exercising leadership means having a clear understanding of and commitment to good science teaching and learning.

It is perhaps impossible to build momentum for an initiative unless decisionmakers believe in the initiative and are committed to its goals. The National Center for the Improvement of Science Education asserts that district and building administrators often don't understand what good science teaching is. Administrators may not need the same level of understanding as classroom teachers, but they must know enough to support and monitor the work (Loucks-Horsley et al., 1989). Effective leaders, "know where they are going, even if they are not quite sure how they are going to get there," writes Philip Schlecty (1992).

Lorraine Blume says she can think of a "million examples" of when her efforts at leadership did not turn out quite as she had planned. But her underlying commitment to inquiry-based science education and to professional development that "maintains a trueness to what we believe," as she puts it, helps her to reflect on her experiences and make them better next time.

Melva Greene in Baltimore offers this advice, "Don't underestimate the importance of believing that the children can do it. I keep thinking about the

people who...believed that, regardless of the composition of the classes, the kids could do it."

Leaders are not always who you think they are.

Identifying people who are best able to exert leadership is not a simple task. Sam Alessi cautions against making assumptions about who are supposed to be the leaders. Sometimes people are selected for leadership based on inappropriate or too few criteria. For instance, enthusiasm, although a helpful attribute, will not itself yield effective leadership.

In Las Vegas, Lorraine Blume found that choosing people who had been previously ordained as leaders was sometimes problematic. They understood leadership in the "old paradigm," she says, and often held fixed beliefs about what a leader was. "It's more difficult to change the paradigm for them," she explains. "It's not always the same person you would have picked out of a crowd before [the reform initiative came along]."

Most practitioners confirm that there is no single process for identifying leaders. They argue that it is most effective to provide opportunities for participation and growth to many people, and then watch as leaders naturally emerge. Sam Alessi advocates continuing interactions and discussions with people inside and outside the district, at all levels, while you "keep your eyes and ears open for those who seem to demonstrate natural kinds of leadership ability: empathy, willingness to reflect, to be collaborative, to accept and offer criticism. Then find opportunities to work with those people." Sometimes, though, there is little time to spare. Susan Sprague, the science program director in Mesa, Arizona, suggests that at the very beginning of a science initiative it is important to start developing and identifying leaders right away. "Try to figure out how many leaders you need," says Sprague, "and then double that number."

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LEADERSHIP RECAP

1. Exercising leadership requires decision-making power or direct access to decisionmakers.
2. Those who want to exercise leadership can be aided with clearly defined responsibilities, adequate support, and opportunities to do their work.
3. Leadership functions best when it is distributed across several people who work as a team.
4. Effective leaders must be credible and have a rapport with and the respect of their colleagues.
5. Exercising leadership means having a clear understanding of and commitment to good science teaching and learning.
6. Leaders are not always who you think they are.

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CHAPTER 5

Curriculum, Instruction, and Assessment

At the front line of systemic reform is the teaching and learning that takes place in the classroom. The three major aspects of classroom work—curriculum (content), teaching, and assessment of student learning—are interlocked like the three sides of a triangle. Though a triangle can reasonably be viewed as three joined line segments, it can also be seen more holistically as one polygon just happening to have three sides. Similarly, curriculum, teaching, and student assessment can reasonably be seen as separate and distinct activities—as they have been throughout much of the course of epistemological inquiry into science education—or as one. Systemic reform sees them as one. They are one, having been interwoven countless times in the daily roundabout of any class of students and their teacher.

While recognizing each classroom as different, school districts need to implement structures and policies that guide classroom work without removing the flexibility needed to spur teacher creativity and meet the needs of diverse groups of students. This notion is embedded in the National Science Education Standards, which include goals and guidelines in all three areas. The standards are just one of many documents available today that define good science education. Others include the Benchmarks for Science Literacy, the work of the New Standards Project, and numerous state frameworks based on these documents. This chapter focuses on some of the lessons learned about implementing curriculum materials, teaching, and assessment reforms.

States and districts should have a guiding curriculum framework document.

Many districts engaged in reform have learned the value of creating a guiding framework, or *course of study*—a document that articulates the knowledge and skills that students should have at particular points in time

and recommends instructional strategies to accomplish these ends (Eisenhower Mathematics and Science Regional Consortia, 1995). Looking back at the earlier days of their reform, Melanie Barron, the science coordinator in Cambridge, Massachusetts, says, "I started inside-out, without a framework. [The] teachers would have probably felt more secure if they had had more of a map of where we were going, but I didn't have one to give them. The work would have hung on a scaffold that had some coherence."

A framework is a district-wide or statewide document that contains a clear and logical set of expectations. It provides a guide for the selection of curriculum materials, it helps teachers choose effective classroom practices, and it promotes coordination and articulation across schools, grade levels, and subject areas. Without such a compact, the opportunity for students to learn a coherent body of knowledge cannot be guaranteed: they may encounter the same topics in grade after grade, their study of science may not complement their study of other subjects, and their intellectual progress may be jeopardized if they change schools. The strains these problems place on teachers can also be considerable.

A framework is a district-wide or statewide document that contains a clear and logical set of expectations.

The development of a curriculum framework offers the opportunity to tap a wide range of perspectives in defining the science program. In some cases, this process in itself produces a deeper understanding of the goals and strategies of reform. Judy Reid, project coordinator for the Earth Systems Implementation Project in Anchorage, Alaska, included teachers and decisionmakers such as school board members, principals, the head of the curriculum department, and directors of elementary education, in her 2-year effort to complete a science framework. "It was sometimes a challenge," Reid admits, "to pull a diverse group of people into the development process and keep them involved in a meaningful way." But there were benefits of having such a group: the multitude of opinions, identification of roles for key constituencies, and the support it produced for teachers during the actual implementation. Reid stresses two points, "Don't underestimate time frames; leave yourself time to do it well. And only have conversations that move the project forward." Time is critical because writing a framework involves making difficult decisions.

Districts must consider local circumstances, state frameworks, and other policies that may impact implementation. In Massachusetts, for example, the

state Department of Education has developed a science and technology framework based on the National Science Education Standards. Now the city of Boston is developing its own standards for every grade, trying to stay within the state guidelines. In Cambridge, planners decided to keep their framework short and focused on key concepts and skills, choosing to create the necessary coherence through the required use of certain curriculum materials. Boston, on the other hand, with its more detailed framework, will not necessarily require the same materials in every classroom.

Articulation and connections across subjects are central to broad and deep student learning and for effective use of time and resources.

Boston and Cambridge illustrate different approaches to providing guidance and coherence to the curriculum framework. If it is too specific, teachers lack the flexibility to select interesting new curricula and to build on the interests and strengths of their students. On the other hand, too general a framework cannot provide the coherence and coordination necessary for an effective program.

Another critical decision is how to coordinate the science framework with those of other disciplines. Articulation and connections across subjects are central to broad and deep student learning and for effective use of time and resources. In Spring Branch, Texas, coordinators of all the major subjects work with teacher teams to develop frameworks, curriculum, and instruction. Particularly important is coordination among science, mathematics, and language arts. When frameworks for mathematics and science are coordinated, the appropriate mathematical skills needed to teach science are taught and reinforced in the mathematics curriculum. When science and language arts frameworks are coordinated, students' communication skills are enhanced through a language arts unit on expository writing and readings within the particular science topic. In New York City Community School Districts 3 and 5, literature libraries accompany every unit, and curriculum teams at each school assist teachers in the integration of the two domains. In Pasadena, California, where students keep science notebooks throughout the elementary years, writing skills have shown marked improvement over time.

A curriculum framework is only the beginning and it may not, by itself, be enough to substantially affect practices in the classroom (NCREL, 1994). A framework is not, after all, a curriculum and will probably seem too broad, too vague, or too laden with objectives to be useful as a guide for teachers'

practice. It is only a scaffold; the building—the curriculum itself—must rise within it.

Schools and districts must provide students and teachers with high-quality instructional materials.

The curriculum is the actual plan of instruction that details the content students are to know, how they are to learn it, the role of the teacher, and the context within which teaching and learning will take place (NCREL, 1994). Having high-quality instructional materials is the next essential piece. Educators find that using exemplary materials is the key to translating the framework into practice.

Exemplary materials are those that

- enhance the knowledge, thinking skills, and problem-solving abilities of all students;
- apply the latest research on teaching and learning;
- engage students in active learning and make appropriate use of technology;
- are content accurate and age appropriate; and
- assist teachers in changing practice.

Good materials also help teachers to teach more effectively and enhance their skills. These teacher-supportive materials coordinate science with other subjects, are comfortable to use, provide day-to-day guidance, and offer teachers the occasion to expand and enrich their teaching skills as they gain experience.

Some districts adopt a single set of materials for all classrooms. In such cases it is very important that adoption policies allow for the selection of curricula that are inquiry- and materials-based and come in modular form. To support the implementation of its science framework, the state of California made its adoption policies more inclusive in 1992, clearing the way for the state board of education to reject inferior texts and choose more innovative materials. Some districts do not have a formal adoption process but require a set of units of study at each grade level. Pasadena, California, Anchorage, Alaska, Cambridge, Massachusetts, and San Francisco, California, all take this approach.

Yet another approach is to allow schools to select their own materials from an approved set guided by a district framework. When Cleveland, Ohio, with its decentralized system, was ready to choose curricula, science coordinator Lawanna White circulated a set of boxes of exemplary materials

among all the schools so that each might determine its own program. This eventually led to a more formal district-wide adoption process.

Some districts supplement purchased curriculum with modules particularly relevant to local issues. Others adapt them in other ways. Many educators argue that teachers should be free to adapt and enrich published materials, but warn them against trying to develop their own from scratch. "Don't write your own curriculum," says Jerry Pine, a professor of biophysics at the California Institute of Technology. "It's too expensive and time-consuming to do it well." Careful curriculum development requires considerable time, resources, and support. Researching, writing, field testing, and piloting a new curriculum is a full-time job that takes years. Few classroom teachers have the necessary support to balance such work with daily responsibility for students.

Schools and districts must have a system for purchasing, storing, and refurbishing materials kits.

Having committed themselves to an inquiry approach to science education, schools and districts must grapple with the need for a system for purchasing, storing, and refurbishing materials kits and getting them into classrooms. It is difficult to gather materials, replace what gets used up, and fix or replace what gets lost, worn out, or broken. Having a good system makes a big difference. "When teachers know they don't have to go scrounging for materials," says Judy Reid, "it removes some of the reasons for them not to teach science."

Businesses, universities, and other organizations can be sources of financial and in-kind support for materials management.

Some districts, like Mesa, Arizona, and Pasadena, California, have a fully staffed central site where materials are purchased, stored, and refurbished. Kits are delivered to classrooms, picked up, and returned on a set schedule, then refurbished and sent out again. This model works well where the curriculum is centrally determined and the district is willing to commit the necessary resources. Many communities have found that such a materials management system saves money. Kits can be rotated among classrooms, reducing the number that must be purchased. Huntsville, Alabama, provides this service to neighboring districts as well as the city itself. In fact, so many districts have created central materials sites that it has given rise to

an organization devoted solely to this purpose, the Association of Science Materials Centers.

Other districts, such as San Francisco, use a partly decentralized model where all materials are ordered by a single office in response to schools' requests. The schools are individually responsible for scheduling and distributing them to teachers. This model may work better where space is at a premium and flexibility is a priority.

Still other districts are fully decentralized. Space is set aside in each school and teachers or other staff are responsible for acquiring, refurbishing, and distributing materials. This model maximizes school autonomy but may sacrifice the efficiency of centralized purchasing and management.

Businesses, universities, and other organizations can be sources of financial and in-kind support for materials management. In some communities such partner organizations provide space, volunteers to staff a center, collection and distribution of excess resources from the community, or transportation. Some even sponsor a particular module or kit. In Buffalo, the Museum of Natural History provided space and staff for materials until it was able to secure a separate building for use by the schools. In Palo Alto, California, Hewlett-Packard offered space in its headquarters where a group of retirees set up a science materials center to serve several local communities. In San Francisco, a corporate sponsor provided funds for purchasing children's books to supplement the modules and kits that teachers were using. Teachers, in turn, were invited to make a presentation to the company's board of directors showing their students' work and demonstrating the impact of the company's investment.

Assessment instruments must align with teaching practices, instructional materials, and expectations at the district level.

Large-scale testing is used for many reasons: to assess the health of the nation's schools, to make districts accountable for the state tax dollars, to ensure equity, to hold principals and teachers answerable for student performance, to inform parents of their children's progress, to place students in special programs or advance them to higher levels, to make students demonstrate what they have learned, and to adjust and adapt instruction to better meet student needs. They are a fact of life at every level of the education system.

Tests that bear large consequences for districts, schools, classrooms, or students hold powerful influence over curriculum and instruction. These high-stakes tests—such as those tied directly to district aid or student pro-

motion—can press teachers to teach what is on that test. This often has not only a major effect on what content is taught but also on how it is taught. Pure multiple-choice, factual recall tests offer strong disincentives to adopting an inquiry approach to teaching and can render inquiry-based reform programs impotent. Those planning a reform process must examine existing policies and tests to see how they align with the goals of the effort.

On the other hand, tests can sometimes result in greater emphasis on science teaching and learning in a state or district. Good tests not only support good instruction but also build community understanding of good science teaching. If science education is to improve, it must become a core subject in the curriculum and must be included among other subjects in tests that hold districts accountable for student performance.

Robert Rothman, author of *Measuring Up: Standards, Assessment and School Reform* (1995), notes, "teachers who choose to focus on what is tested must leave something else out. In some extreme cases, whole subject areas are left out, at least for part of the year. If the state tests students in reading and mathematics, for example, teachers may put off instruction in science and social studies until after the test." Few districts may admit to this practice, but it is frequent in many states where reading and mathematics tests are strongly emphasized.

Testing policy and tests themselves must change to reflect new approaches to learning. The current reform movement advocates active learning, deep engagement with an idea rather than learning a large number of facts, and an emphasis on scientific reasoning and inquiry skills. Too often tests and reform programs remain at cross purposes. Simply put, tests must measure what is valued and taught.

New Ways to Assess Learning in Science (Swartz, 1991) contains a number of examples of poorly designed and well designed test questions that illustrate the importance of quality testing. Taken from this source, the questions below are designed to test students' knowledge and understanding of endangered species and extinction.

1. Which of the following species of animals is now extinct?
   a) the African Elephant
   b) the Dinosaur
   c) the Horse
   d) the Gypsy Moth

2. True or False: Animals are said to be endangered if they no longer exist.

Correct responses to these questions may come from a real understanding of extinction, may reflect the student's familiarity with these particular facts and definitions, or may be lucky guesses. From the student response alone, it is not possible to tell. When tests emphasize factual multiple-choice and true-false questions, teachers and students are less motivated to explore the topic in a deep and intellectually meaningful way.

3. When prairie dogs are near farms they eat farmers' crops. Because of this, farmers have killed thousands of prairie dogs. Black-footed ferrets eat prairie dogs. Explain what problem this poses for the ferrets and why this is a problem.

4. Suppose you were asked to observe the feeding habits of black-footed ferrets so that you could gather some data about this problem. Describe what you would do to make sure that your observations were as accurate as possible and that you brought back data that other people could trust. Write out a plan listing all the things you would think about beforehand.

Open-ended questions like these provide information not only on what children know but also on how they use what they know—they reveal the thinking processes of the test-taker. A fourth-grader's response to Question 3 follows:

> If there aren't enough prairie dogs for the ferrets to eat many of them will starve to death. That's because prairie dogs are their main food. If the farmers kill most or all of the prairie dogs, this will be a big problem because most of the ferrets might die. This would mean that their population would become very low. This would mean that they could become endangered species. And if they all die they would become extinct. Then there would never be any other ferrets. And maybe this would not just be a problem for the ferrets. If other animals depended on the ferrets for their food, they could become extinct too.

This response demonstrates that the student understands quite deeply the concept of extinction and can use this understanding to explain the broader scientific connections and consequences of extinction. Contrast this response with question one, the ability to identify dinosaurs as an extinct species. It is not only more complex, it is more meaningful, powerful, and relevant. This is why the inquiry approach and systemic reform place such value on depth of understanding and the ability to use it. But teaching for this kind of understanding takes time, and it means making tradeoffs in the curriculum—not teaching something else.

Open-ended questions are one type in a group of so-called alternative assessments. These include a variety of strategies: exhibitions, performances, demonstrations, hands-on experiments, journal writing, computer simulations, and portfolios of student work (NCREL, 1994). Some cognitive scientists and education reformers, such as Theodore R. Sizer, argue that performances and exhibitions are the kinds of assessments that test instruction that leads to true learning. They demand much of students. Students must demonstrate their learning in the real-world context and exhibit a range of abilities, not just specific skills and factual knowledge (Rothman, 1995).

The disadvantage of open-ended questions and other alternative assessments is that they are costly, difficult to create, time-consuming, and difficult to score. There are many questions about the feasibility of their use, particularly on a large scale. But interesting work is in progress in many places.

Some assessments are being developed at the classroom and school levels that are directly related to the curriculum. In Pasadena, teachers are using student science notebooks as assessments as well as performance tasks. Jerry Pine, a scientist partner in Pasadena, contends that "performance assessments for grades K-6 should be linked to the curriculum." The Pasadena model is being implemented in part by teachers who are well versed in teaching inquiry-based science in collaboration with scientists and assessment consultants. The starting point for developing the assessments is usually the embedded assessments found in exemplary commercial curriculum units.

There are still many challenges[1] to be overcome: how to create cost-effective assessments, how to score them objectively, and how schools and districts can use them effectively for accountability. Science education

[1] Robert Marzano, deputy director of training and development at the Mid-continent Regional Educational Laboratory, has created some useful rubrics for scoring performance tasks. The rubrics are based on the various skills that students are expected to develop and demonstrate (see *Assessing Student Outcomes* by Marzano and colleagues).

reformers must find a way to satisfy both the demand for accountability—what is happening at state, district, school, and classroom levels—and the need to develop appropriate and useful measures of what the reform effort values. It is not enough to condemn traditional multiple-choice testing. Reformers themselves must begin to offer alternatives. In the meantime, however, teachers must invest themselves in making valuable use of testing and making testing a valuable part of teaching and learning. They must sharpen their ability to use tests to guide instruction, to measure the development of their students, and to provide parents with accurate measures of their children's work.

CURRICULUM, INSTRUCTION, ASSESSMENT RECAP

1. States and districts should have a guiding curriculum framework document.
2. Schools and districts must provide students and teachers with high-quality instructional materials.
3. Schools and districts must have a system for purchasing, storing, and refurbishing materials kits.
4. Assessment instruments must align with teaching practices, instructional materials, and expectations at the district level.

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CHAPTER 6

Professional Development

Inspired to retake control over their own professional growth, 10 elementary school teachers in Cleveland, Ohio, established a study group they named "Journeys." The teachers met once or twice a month to improve their skills in inquiry-based teaching, coaching, and mentoring, and to discuss ideas about learning theory. "[We] developed a new culture for learning," says science resource teacher Bill Badders, who organized the group several years ago. It has provided the opportunity "to reflect honestly and openly about our pedagogy, our content understanding, our knowledge of teaching, and our ability to assess both ourselves and our students" (Badders, 1996).

Educators are moving away from fragmented, piecemeal offerings to coherent professional development plans organized around school and district goals for educational improvement.

Although self-initiated, Badders's study group is an example of the innovative ways educators are thinking about professional development—a vital element in any systemic reform effort. Historically, professional development consisted of a menu of offerings: discrete sessions that teachers would choose from, based on their individual interests. But some researchers now argue that these more conventional forms of enhancement are ineffective, primarily because they are designed in isolation of teachers and do not address the realities of the classroom (Corcoran, 1995).

Educators are moving away from fragmented, piecemeal offerings to coherent professional development plans organized around school and district goals for educational improvement (Sparks, 1994). Random, packaged events are being replaced by programs that engage teachers in an ongoing

process of reflective learning (Regional Laboratory for Education Improvement of the Northeast and Islands, 1995).

With these changes, knowledge of what makes for meaningful, effective professional development has grown. The National Science Education Standards (1996) are among works that identify the characteristics of good professional development: collegiality and collaboration; participant involvement in decisionmaking; experimentation and risk taking; and integration of individual, school, and district goals (Arbuckle and Murray, 1989). Perhaps most important, professional development must be "based on what is known about learning and the process of change" (Loucks-Horsley et al., 1987).

In the move toward improved professional development, educators have stumbled upon a new challenge: the skills and interests of teachers and administrators are ever-changing. As a result, they are seeking ways to balance professional development that is geared toward particular levels of understanding and experience with the needs of teachers, schools, and districts to remain flexible and adaptable. In this chapter, educators share a number of lessons about how to design professional development to maximize the improvement of science education in their schools.

Schools and districts must redefine professional development and find innovative, flexible ways to create and manage time for it.

Teachers need professional development experiences that give them opportunities to share knowledge, to connect their learning directly to the context of their teaching, and to gain leadership expertise (Darling-Hammond and McLaughlin, 1995). Strategies often include peer coaching, researcher experiences, journal writing, mentoring, networking, and study groups like the Journeys project in Cleveland.

In Mesa, Arizona, science program director Susan Sprague believes these alternative approaches are gaining ground. As the skills and interests of teachers evolve, the Mesa program puts less emphasis on introductory curriculum workshops and other forms of *information giving* and focuses more on contemplative, collaborative learning. These strategies allow teachers, who often work in isolation, to reflect on experiences, spend time in each other's classrooms, and get feedback from those who know their schools and students best—their fellow colleagues.

Greg Knisely, a professor at Rhode Island College, is experimenting with another approach. He works with a consortium of school districts on a jointly run, NSF-funded project called KITES—Kits in Teaching Elementary Science. The project pairs experienced teachers from the districts with

college students who are training to become teachers. The experienced teachers prepare inquiry-based science instructional materials and then introduce them into their classrooms in collaboration with the teacher-trainees.

Linda Gregg, the administrative specialist for K-5 mathematics and science in Las Vegas, also uses classroom collaboration as a form of professional development. Teacher-leaders conduct science lessons in classrooms while the class teacher learns by reflective observation. Because this takes place in their own classrooms with their own students, teachers who might ordinarily be reluctant to teach science gain confidence and insight into their own abilities as well as those of their students.

Many of the professional development solutions that educators have created require a new approach to scheduling, staffing, and grouping arrangements, rather than a great deal of money or work.

However, these communities have discovered that the absence of time for professional development is a constant impediment to teacher growth. Although Lorraine Blume, a teacher-leader in Las Vegas, has been fully released from regular classroom duties, she cannot find enough time for everything she believes is important for effective professional development. Her colleague Linda Gregg feels the same way. "There just isn't enough time for the thinking and planning that professional development requires." As a result, both constantly seek new ways to manage their time.

Many of the professional development solutions that educators have created require a new approach to scheduling, staffing, and grouping arrangements, rather than a great deal of money or work. (Harvey, 1995; Darling-Hammond and McLaughlin, 1995). Carmen Quintas, assistant principal at New York Public School 98, found a way to provide professional development during the school day. She worked with the assistant principal in charge of scheduling and created opportunities for teachers to have what Quintas calls "mass preps." All of the teachers at one grade level got a common planning period that they use for grade-level professional development. This not only resulted in more time for professional development, it contributed to the formation of a growing learning community among faculty and staff, and in turn helped to make professional development an "integral part of [the] teachers' work" (Corcoran, 1995).

Professional development programs must be led by teams that include members with scientific expertise and must incorporate activities that model the kinds of effective science teaching and learning that is expected to take place in classrooms.

Researchers agree that regardless of the approach taken, professional development should reflect the best of classroom practices (Loucks-Horsley et al., 1989; Corcoran, 1995). "We can't talk at teachers," says Melanie Barron, science coordinator for Cambridge, Massachusetts, and leader of the NSF-funded Habits of Mind teacher enhancement project. "Instead, we do with them what we want them to do in the classroom. If you want your teachers to have children learn from the environment, you have to take them to a pond for a sampling expedition."

Professional development leaders also need to practice the pedagogy they are trying to promote. Jennifer Moore, of the Cambridge project staff, explains that they want teachers to identify and respect students' prior knowledge, so they try to respect teachers' experience and knowledge during professional development.

Lorraine Blume cautions that change does not come about instantaneously and can be hard to maintain. She sometimes even finds herself falling back into old habits. "Fifteen years ago, I was a traditional teacher," she explains. "I still see little bits of that come to the surface; if I don't catch it until after I am done, it can hurt the professional development because then I'm not walking my talk. Whatever we believe about how kids learn we have to believe about how adults learn. Not that we should treat adults like children, but it is a good reality check so we don't fall into the old paradigm." Blume says she has to laugh when she finds herself reverting to bad habits. "I just say to myself, 'There's still more work to be done.' "

Professional development programs must allow teachers to see and experience good science teaching firsthand. Mesa, Arizona's Susan Sprague observes that teachers and administrators need "lots of operational definitions of what good science looks like," and suggests that even if they have to go to another community to experience it, it is worth the trip. Furthermore, she adds, teachers need many direct experiences using good materials in order to reach the basic comfort level required for further growth. Lorraine Blume notes, "It's important, particularly with science, to start with the materials so that teachers have a common experience that they can speak from."

Professional development programs should encompass a range of teacher experience and, for all teachers, extend over a long period of time.

Effective professional development arouses in teachers an ambition for lifelong learning—continuous advancement in knowledge and experience no matter what the age or professional condition of the teacher (Harvey, 1995; National Research Council, 1996).

Specialists now realize that for this type of professional development to become commonplace, they have to develop sequences of learning that build on one another; support ongoing development over long periods of time; and consider the diverse needs, interests, and experiences of the participants. But, it is not easy to design long-term professional development programs that effectively advance teacher growth and maintain momentum over the course of years. One community decided to begin its science education reform by introducing teachers to the science materials. The following year, they focused on strategies like cooperative learning and questioning. The next year they tried to initiate study groups. Eventually, the science coordi-

STARTING FROM THE BEGINNING IN HUNTSVILLE AND DECATUR, ATHENS, FORT PAYNE, SCOTTSBORO, AND MORGAN CITY SCHOOLS

Arlene Childers—a former Huntsville, Alabama, teacher who is now a director of the NSF-funded Hands-On Activities Science Program—knew that many teachers were at the starting point of using inquiry-based materials and would need firsthand experience with the materials over an extended period of time.

She and her colleagues resolved to begin slowly. They developed a plan that brings teachers together twice a year for a full day of professional development focused only on the curriculum modules. The first day—devoted to questions the teachers have about instruction and content—occurs at the beginning of the school year; it is timed when teachers actually begin to use the materials.

"It was important to consider how teachers learn and their need to have concrete experiences with the curriculum," says Childers. Then, in the middle of the year the teachers reconvene to fine-tune their expertise. This time, they focus on additional portions of the units, ask questions about things that were not working, share experiences about what works well, and discuss new ideas intended to move the entire group forward. This way, the teachers have a chance to make some adjustments in their practice before the end of the school year. This is only a small part of their larger program, but it is an important necessary foundation for teachers just beginning and for teachers building more meaningful experiences over time.

nator found that even though teachers were participating in the program, their needs and interests did not necessarily mesh with the professional development plan. They had to create a new structure that was more flexible and would allow for individual as well as group progress.

Collaborating with established science institutions to support teachers' learning is a critical component of professional development that can fill in gaps in understanding and expand overall content knowledge.

A flexible, diversified plan is also important for communities that have a high rate of teacher mobility from grade to grade and in and out of the school system. One science coordinator, for instance, was in the fourth year of his reform program and thought that nearly all his teachers had participated in science professional development. He discovered, when he looked more closely, that 20 percent of the teachers who had begun the program were no longer in classrooms and 35 percent of the teachers had switched grades. The coordinator learned that moving from discrete professional development activities to sequences of activities was not enough. His program needed to be redesigned as a continuum of experiences to support an ongoing process of growth, but it also needed to remain flexible enough to accommodate teachers with different levels of expertise (Loucks-Horsley et al., 1989). The bottom line is that, every school and district will always have teachers at all stages of professional development.

Professional development has to happen over time because teachers need long-term experience in developing and honing new skills. At P.S. 98 in New York City, professional development takes place in continuous 4-week cycles. Carmen Quintas sees it as similar to planning for student learning. "You work on one area and concentrate on that and when you are ready to move on, you move on."

Andrea Bowden, supervisor of science, mathematics, and health in the Baltimore Public Schools, learned this the hard way. Under pressure to produce quick results, she was tempted to do "too much too soon." Melva Greene, her colleague, elaborates, "We set out to give people the world in one step...the pace was so tremendous that the teachers never learned step one well before we went on to two and three." Professional development

activities, say Bowden and Greene, should be carefully sequenced to allow time for teachers to build expertise.

Effective professional development also accommodates the participants' range of interests and prior knowledge. Lorraine Blume found that professional development sessions she facilitated, "didn't quite become what I wanted them to become," because she failed to understand what her audience wanted or expected. Now she assesses what participants already know and what they want to know. "It's deadly to assume that everyone is going to come in with the same mindset," says Blume, "so I learned to be better at asking participants what they expect—quite often changing my plan."

Many teachers avoid teaching science because they lack experience with the content and have little confidence in their ability to teach it. "Most college programs do not prepare teachers well to teach science," says Sandy Lam, program director for curriculum improvement and professional development in San Francisco. Making this challenge still more daunting is the demands inquiry-based science places on teaching. Inquiry-based teaching requires a much deeper understanding of content than the more traditional approaches to teaching. As a result, professional development programs must be pliable enough to accommodate a range of levels of content understanding.

CHANGING HABITS OF MIND IN CAMBRIDGE

"There hasn't been a talk except for where they've asked for it," muses Melanie Barron, science coordinator in Cambridge MA, about her professional development program for five teacher-leaders.

Her leaders are making the difference for science teaching in the district. Barron has been working with a grant from the National Science Foundation to implement the Habits of Mind program to improve science teaching in Cambridge, kindergarten through eighth grade.

The program includes professional development for classroom teachers, but uses five science staff development teachers to provide most of the classroom support. According to Barron, they are key in the development of the program throughout the district. All were teachers relieved of classroom responsibilities to support other teachers' science teaching full time.

"[I] poured everything into supporting them, " Barron remembers, customizing to their needs and addressing a wide range of topics in a variety of ways. "We have had every flavor...working with scientists, planning, organizing, writing grants, working with local university students. There hasn't been a talk except for where they've asked for it," she notes again for the sake of emphasis. "Now, after two years, they are totally in charge of their own learning. They know what resources I can deliver and they tell me what was effective."

Collaborating with established science institutions to support teachers' learning is a critical component of professional development that can fill in gaps in understanding and expand overall content knowledge. In Buffalo, for example, the school system works with the Museum of Natural History. In most efforts, however, educators collaborate with higher education institutions to identify science professors and research scientists that understand this team approach to professional development. Others are working directly with scientists to help them shift their teaching styles to fit this new approach. Teachers and scientists at Cal Tech in Pasadena are supporting such instruction by developing modules to improve and broaden teachers' content knowledge. Teacher-scientist teams will lead groups of teachers in what they describe as "an inquiry-based learning community like that of an exemplary classroom."

Finally, it is essential to recognize and plan for an often-shifting population of teachers. In Mesa, Arizona, the strategy of continuous professional development has evolved to better accommodate the needs of new teachers. A mentoring program has, for the most part, taken the place of introductory workshops on the modular curriculum Mesa uses. Each new teacher receives customized attention and support by being paired with an experienced teacher for the year. The experienced teachers benefit as well; they become even more comfortable with the instructional materials and deepen their own understanding. As strategies like this one emerge, educators will continue to make professional development a more effective tool in improving science education.

Teachers value professional development that is created onsite and led by other teachers and colleagues they respect.

Through their mentoring program for new teachers, Mesa, Arizona, administrators learned the value of professional development based at the school site and conducted by respected teacher colleagues. This approach embeds professional development in the workplace and directly relates it to teachers' real classroom experiences (Corcoran, 1995). It allows for teacher input into professional development so that it is planned and owned by the teachers themselves. And, to the extent that teacher-leaders are ready, professional development can be run by their fellow teachers.

School administrators need to seek out and mobilize resources for professional development within their schools. One teacher-leader says he has grown professionally because his principal gives him opportunities to pursue his interests and the authority and responsibility to lead projects in the

school. Another teacher in the same district is capable of leading professional development work with colleagues and eager to try, but has been overlooked by her principal. Such shortsightedness "wastes talent, increases costs, and contributes to the division between research and practice" (Corcoran, 1995).

Teacola Offett, principal of Orchard Elementary School in Cleveland, recognizes the talent in her own school and uses it. She explains that first she got to "know the teachers" and then identified one teacher in particular, Corlista Hardman, who was outstanding in the classroom. Though shy, Hardman wanted to get involved. Offett made her a teacher-leader in the district's science education program, Cleveland Revitalizes Elementary Science Teaching (CREST). Hardman was put in charge of the school's involvement in CREST and worked with the staff to help plan professional development. Now, several years later, Hardman is recognized across the district as a leader in science education.

Carmen Quintas in New York City confirms that some professional development is more widely accepted when it comes from teachers in her own school. "They're very receptive to their colleagues doing professional development," says Quintas, "and in many cases it is better received coming from them than from a supervisor or from district personnel, because they are people out there in the 'battlefield,' not just people who are telling them what they should be doing."

The teaching practices promoted in professional development need to be supported by district and school administrators.

One thing has proven itself over time—there will be little meaningful change unless the goals of a professional development program are aligned with larger school or district goals. Considerable research shows that active support by principals and district administrators is critical to the success of any change effort. Carmen Quintas recalls that the superintendent in New York's District 6 told all school administrators that the science program was to be supported; the administrators in turn communicated that message within the schools. After this clear message, "the principal paved the way," says Quintas, and the program took off.

Despite the boost Quintas received, generally speaking, support of the administration has to go beyond just the logistical. It also must become more than a mandate. After working for many years in urban school systems, the Center for Urban Science Education Program (CUSER) has found that quality science education must become everyone's responsibility—teachers and

administrators. Principals need to work closely with teachers not only to provide support, but to augment their own knowledge of science education.

Linda Gregg in Las Vegas believes that it is important for principals to understand the role of the teacher and what constitutes an appropriate science lesson. But they also must understand that it takes a long time—they will not see changes immediately. "Everybody expects professional development to be reflected the next day," says Gregg. "Do it Monday and see test scores up by Friday. It just doesn't happen."

Teacola Offett of Cleveland agrees, "the principal has to be very involved. When it first gets started, you definitely have to [have] a hands-on principal. [Teachers] have to see that this is important enough that the principal is physically there—not only in [the] reports." This is the essence of a systemic approach to improving science education. The responsibility for reform rests not only with teachers but also with district administrators, principals, counselors, parents, and community leaders (Kober, 1993).

PROFESSIONAL DEVELOPMENT RECAP

1. Schools and districts must redefine professional development and find innovative, flexible ways to create and manage time for it.
2. Professional development programs must be led by teams that include members with scientific expertise and must incorporate activities that model the kinds of effective science teaching and learning that is expected to take place in classrooms.
3. Professional development programs should encompass a range of teacher experience and, for all teachers, extend over a long period of time.
4. Teachers value professional development that is created onsite and led by other teachers and colleagues they respect.
5. The teaching practices promoted in professional development need to be supported by district and school administrators.

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CHAPTER 7

Financing Science Education Reform

Many reform projects are launched using a mixture of local school funds and an initial infusion of external grant money. Although possible to finance with district or school resources alone, many districts just cannot do it without some outside help. Obtaining these startup dollars requires considerable planning. It means identifying potential sources of funding, researching the priorities and grant-making criteria of the potential funders, and writing a proposal that persuasively links the funder's goals with the needs of the district reform project. Once the initial funding is secured, it is essential to begin immediately to identify and reallocate system resources in order to guarantee the effort will be sustained.

Ultimately, the goal of systemic reform in science education is not just to change classroom practice for the day, but to institutionalize those changes over time. It is tempting to assume that long-term, external financial support is the answer. Although attractive, external support rarely lasts indefinitely, and—most importantly—does not substitute for the major overhaul in system resource allocation required to make ongoing improvements in teaching and learning. The real challenge, then, is not attracting the startup funding, it is sustaining the momentum of reform when the initial funding dries up.

For those with little or no experience in raising money, the prospect of financing a complex, long-term science education reform initiative, even in one school, can seem daunting indeed. Fortunately, others have been through the process and share their advice.

Science reform planners can often get seed money from local, state, and federal funders.

Seed money is a term used to describe an initial grant—money earmarked to support the earliest stages of a project, often before an overall plan has been developed. It can come from a variety of sources: in this case, the National Science Foundation (NSF), Goals 2000, the federal Eisenhower

program, or local foundations or corporations interested in supporting science education reform. Some grants, like those awarded through the NSF's Local Systemic Change and Urban Systemic Initiative programs, are designed for the specific purpose of supporting systemic change, rather than discrete, isolated curriculum, research, or professional development projects.

The most successful projects combine federal funding, local district funding, and partnerships with universities, museums, and corporations.

Seed money for systemic change sometimes takes the form of an initial planning grant. These are funds designated to offset the costs of careful planning, which, as we noted in CHAPTER 3, is itself a complex, ongoing process. Planning grants can help pay for release time for teachers so they can participate more fully in shaping the school's or district's reform program. Such grants can also finance site visits to districts that have been successful in instituting improvements in science education.

Successful fundraisers are entrepreneurial. They develop multiple contacts and networks among educators, government officials, local business people, foundations, and cultural institutions. It is important to contact a wide group of experts as soon as possible and to follow up quickly on their suggestions. The most successful projects combine federal funding, local district funding, and partnerships with universities, museums, and corporations.

Pursuing seed money, however, is not the only direction a community can take, and is not necessarily the only starting point. External seed money is enormously helpful in launching a reform program, but the driving force behind the project must be a sincere commitment to reform, rather than a sincere desire to get the grant. The award often depends on having the first steps of the project already under way, and all grants require a commitment of human and financial resources on the part of the district.

Most funders require evidence of cost-sharing on the part of the district. Sam Alessi, the assistant superintendent in Buffalo, says "before we even apply, we're sure we have the…meshing with the district's goals, the superintendent's support, and backing of the board. We wouldn't even go for the funding if we didn't." Taking the position that "we can't start until we get funded" is therefore counterproductive because it places money—not science teaching—at the center of the enterprise, which can actually interfere with successful fundraising efforts.

Districts should establish a system of development.

Development in this context is just a widely used euphemism for fundraising. Some school districts, recognizing the importance of outside funding, have hired full-time development directors to manage fundraising activities. Other communities organize committees of teachers, community members, principals, and other administrators who identify potential funding sources, develop funding strategies, and participate in the actual writing of the proposals. This kind of broader effort signals funders that there is widespread acceptance of and commitment to the proposed initiatives.

Research and writing are vital parts of developing a proposal, but equally important is the ability to create and sustain strong personal relationships both with funders and with the leaders of local partner organizations. Effective development work often involves maintaining close ties to news organizations that can help inform the community about the purpose of the science education reform initiative. It also involves building bridges to business, industry, and institutions of higher education that have a stake in a better educated student population.

Funders themselves frequently become active participants in district development efforts. Partner institutions like corporations and universities can give a science education reform project added credibility in the eyes of the community and encourage other organizations to get involved. The Dow Chemical Company, for example, has been promoting science education reform in 14 communities, offering both financial support and the time and energy of Dow scientists. Dow has taken their commitment a step further. It is now helping schools raise additional funds by approaching other corporations, community organizations, and local and national foundations on their behalf.

Similarly, the Allegheny Schools Science Education and Technology (ASSET) program in Pennsylvania started with funding from the Bayer Corporation, but has since developed into a major community project with many partners. There are now 15 different funders supporting the program, including NSF.

Change always takes longer than anyone expects; therefore, seek a variety of funders and develop long-term relationships with them.

A one-time infusion of grant money is not enough to bring about a program of systemic change. Therefore, districts need an overall funding strategy that includes all sources of external and internal support. Each interested funding source should be encouraged to make a commitment covering

several years, rather than a single-shot contribution. Funders must understand that schools change slowly and that their investment in improved science education will be more likely to take hold if, in addition to their financial support, they also get involved.

Such support does not have to be extensive to be valuable. In Cleveland, for example, one company provides teachers with a comfortable place to meet every month—a small offering that nevertheless makes a big difference to teachers in a financially strapped urban district. Another corporation provides the Cleveland district with funds for materials; yet another involves its scientists and engineers in the district's professional development program.

Needing to find multiple funding sources does not mean that districts should actually apply for every available grant. In Buffalo, the grant-writing operation is in the same department as curriculum to ensure consistency and coherence between what the district is trying to do and the funding it seeks. Some grants may have terms or conditions attached to them that are incompatible with the goals of the reform program. Corporate contributions are sometimes tied to the use of specific curricular materials that just do not fit the plan. Federal and state funds often come with restrictions that limit program options. The goals of the reform effort must always drive the fundraising work, not the other way around. This means that some potentially promising funders will have to be passed up.

Do not let the seed money become the program; from the outset, work to identify the real costs of reform and to reallocate district dollars to support it.

Science education reform is an ongoing process, as is paying for it. Not only does a district have to buy new classroom materials—like instruction kits used in hands-on science activities—but it also has to regularly replenish the seeds, guppies, and other consumable contents of the kits. Similarly, the need for professional development for teachers and administrators does not diminish with time, as we noted in CHAPTER 6. These are costs that, ultimately, should be covered by each community through its regular school funding sources, not through seed money for a startup project.

Some districts support ongoing science education reform by reallocating funds from other programs whose goals are advanced by the implementation of inquiry-based science teaching. These programs include school-restructuring initiatives; mentor-teacher programs; and Title I, Chapter 2, Eisenhower, migrant education, and Title VII funding from the U.S. Department of Education.

Community School Districts 3 and 5 in New York City have leveraged funds from a variety of sources to finance science education reform. The two districts received an NSF grant for their Science, Mathematics, and Related Technology Process program, (SMART Process) to change the culture of schooling over a 5-year period. Gil Turchin, special assistant to the superintendent of District 3, says that the NSF money, $1 million a year, represents only about one-third of the real cost of the project. The other $2 million comes from various state and district programs. Title I funds, made available to schools serving economically disadvantaged students, are used to support teacher-leaders in each school. Money earmarked for textbook purchases is reallocated to buy science kits. The project also has a 1-year empowerment grant of $325,000 to buy science and mathematics manipulatives.

Some districts support ongoing science education reform by reallocating funds from other programs whose goals are advanced by the implementation of inquiry-based science teaching.

Turchin breaks down the costs of the program into expense categories, then finds the funds to cover them. For example, NSF money pays for half the cost of four staff developers; Title I funds covers the other half. NSF pays for a project coordinator and a principal investigator; Eisenhower funds pay for two co-principal investigators.

The long-term financing of professional development is especially challenging, and calls for creative use of district resources. "Reallocating resources is more than shifting small, discernible pots of money," says Brian Lord of the Education Development Center, who conducted a study examining the costs of professional development in four communities. "It means looking imaginatively at what is meant by professional development and where those resources might be accessed."

Some districts have given science reform leaders considerable leeway in reallocating funds. In Mesa, Arizona, Susan Sprague persuaded district administrators to use funds slated to buy textbooks for the professional development that better supported the goals of the reform. Other districts are more rigid in their policies—or simply too strapped for money to allow for any leeway.

To sustain its professional development program over the long term, the Elementary Science Education Partners (ESEP) project in Atlanta has developed a team of lead teachers to institutionalize the process of teacher training. The system of teachers training teachers will ideally take root in the school district's permanent infrastructure, with the ultimate goal, according to project director Robert DeHaan, of "putting ourselves out of business."

FINANCING RECAP

1. Science reform planners can often get seed money from local, state, and federal funders.
2. Districts should establish a system of development.
3. Change always takes longer than anyone expects; therefore, seek a variety of funders and develop long-term relationships with them.
4. Do not let the seed money become the program; from the outset, work to identify the real costs of reform and reallocate district dollars to support it.

CHAPTER 8

Collaborators in Reform

Schools cannot truly reform science education without the active collaboration of key organizations in the local community. Parents, museums, business, industry, institutions of higher education and various other organizations can lend the critical expertise and support for reformulating a system to effectively educate children in science. Schools are more than just buildings, they are systems—and systems transcend physical space. And, so, the partnership, under the systemic reform model, can be likened to something of a town meeting hall for science education—a place where all resources come together to support inquiry-based science education reform.

Just as systemic reform calls for new kinds of curriculum, classroom practice, financing, and planning, new kinds of partnerships need to be developed and put in place. Building relationships with outside groups is not a new idea, but what is new is the character of the relationships that are being developed. Traditionally these collaborations took the form of isolated projects, events, and field trips. Replacing these disparate activities are long-term partnerships where organizations play specific roles based on their unique resources and expertise. These roles directly support the district's reform goals and complement the functions of other collaborators—each piece must snap into place. Moreover, systemic reformers are constantly redefining collaborations to make them more effective and to embed them within the system so they are able to withstand changes in the schools and community.

In working with schools, outside entities such as corporations and museums were frequently viewed as the giver, while the school or district played the role of *receiver*. Today, the most powerful and successful collaborations recognize that all partners have something to gain. The partners have certain needs that must be served by the collaboration. Those needs vary from partner to partner, but all parties can expect at least one payoff: learning. They will learn from each other and about each other. Liesl Chatman, executive

director of the University of California San Francisco's Science and Health Education Partnership, explains: "It is only a partnership if both teachers and scientists are learning.... Scientists aren't just there to work with teachers on education reform; they are there to learn themselves" (How scientists benefit, 1995).

Organizational culture differences can be an early stumbling block in building effective partnerships. The culture of schools and that of potential partners can be miles apart. The best way to bridge the gap is to understand and directly acknowledge those differences. At the heart of effective collaborations is the development of a relationship based in trust, mutual respect, and effective communication. As Joyce Epstein writes, "Although the interactions of educators, parents, students, and community members will not always be smooth or successful, partnership programs establish a base of respect and trust on which to build" (Epstein, 1995).

Finally and most importantly, participants in successful collaborations recognize their shared interests in the well-being of the children and the community, and they work side by side to create better programs and better schools (Epstein, 1995). There are many such effective partnerships that offer lessons about creating effective and lasting collaborative relationships.

Formal partnerships with institutions can be a valuable strategy but must be genuine and carefully planned.

Museums, businesses, parent and community groups, and universities can be extremely valuable storehouses of expertise and resources for schools. They provide students and teachers with access to materials, knowledge, and ways of thinking not typically found in classrooms. The best use of these resources, however, is made through a reciprocal, rather than a give-and-receive, relationship. The exchange of ideas and experiences between school-based and institutional participants must be mutually beneficial.

Peter Dow, director of education at the Buffalo Museum of Science, says that a "partnership closes the gap between the frontier of knowledge and schools. It allows you to get beyond the inert textbook." Museum curators and schools, for example, can be resources for one another. Curators do not abide by a fixed curriculum as schools do, so often they can develop creative ideas for exploring a science topic or enriching a kit that is in use in the schools. In turn, museum-based educators may have little contact with new developments in pedagogy and instruction and can learn a great deal from teachers about how to effectively engage the visiting public. Working

independently of schools, a museum might have created a high-interest program that is unfortunately unconnected to the school curriculum. But, this setup fails to make good use of scarce school and museum resources. As collaborators, however, the museum and school can align the museum program to the school's curriculum and learning goals, thereby increasing the impact of each side's program.

Scientists from the private sector also represent a rich, current source of science knowledge that can support professional development and the curriculum. Often, however, their view of classroom practice is shaped by their own memories of school and lacks the professional teacher's knowledge of more contemporary perspectives on learning and cognition and how to make practical changes in classroom. Clearly both parties stand to benefit from collaboration.

The Merck Institute for Science Education is moving beyond more basic collaborations on curriculum in order to support the entire reform programs of four school districts in New Jersey. Their work, backed in part by the National Science Foundation's Local Systemic Change Initiative, promises to impact more than individual classrooms. Merck has provided financial and human resources for science education reforms that will benefit both partners in many ways, now and in the future. Carlo Parravano, director of the Merck Institute, explains that "Merck has made an investment in education, not a contribution or donation. We're interested in a return on our investment." To that end, Merck has commissioned studies by the Consortium for Policy Research in Education to document the program's strengths and weaknesses. Such studies go well beyond what ordinary school systems can do on their own and indicate much about the seriousness of the collaboration. Through this collaboration, the school system, the community, Merck, and the entire education field will all benefit.

Collaboration can benefit many parties, but no one will benefit without the development of trust and respect among the partners. Recognition of mutual benefits for collaborating partners is the beginning of the formation of trust. Recognition of mutual expertise is the beginning of respect. Both are required to make partnerships thrive.

Peter Dow, who wrote a book about education reform in the 1960s, explains, "Most sixties school reforms fell by the wayside because they were never organically connected to the school....[They] didn't take into account the imagination of teachers—or their reality." The failure to bring teachers into the partnership resulted in miscommunication and mistrust. Systemic reform efforts today must not make the same mistakes; they should involve

all participants in the system to strive for common understanding and mutual respect.

Robert DeHaan, professor of anatomy and cell biology at Emory University in Atlanta, understood this at the outset. He decided to become involved with the local school system and contacted his grandson's principal. He had his own motives for working with the school but sought to work in partnership. DeHaan met with four of the school's teachers and asked them, "If I could bring you in contact with the science community at Emory, what would you want from us?" DeHaan's wide-open question evidenced respect for teacher knowledge about the best way the university might be able to assist them. Two years later, after much collaborative work, DeHaan is one of the leaders of a Local Systemic Change project, the Elementary Science Education Partners Program, which is built on a partnership that includes a consortium of universities and the Atlanta Public Schools.

The Merck Corporation came to understand the importance of trust and respect in a different way. In their first year of working with schools, they contracted an outsider to run professional development workshops. Many teachers were disappointed because the materials and activities used during the workshops were not a good match for their curriculum and students' grade levels. Merck realized that planning the workshops in isolation had been a mistake. Now, teachers are collaborators in the planning and delivery of the workshops. Merck has also since staffed its science education center with former teachers. Like many institutions, Merck discovered that it had to work in collaboration with the districts if it wanted to effectively support science education reform.

These lessons may hold true for partnerships in any subject area, but there are some lessons unique to partnerships in science education. If developed thoughtfully, with recognition of mutual benefits and with trust and respect, partnerships of scientists and engineers with master teachers for the benefit of improving staff and curriculum development can be very effective. But it is not an easy task.

Working scientists and engineers embody the inquiry-based approach to science that educators are working to promote. Scientists pose questions, design experiments, observe, record, and analyze data and can provide a model for scientific thinking. But they do not always know how best to work with children and teachers. As Bruce Alberts, president of the National Academy of Sciences, has written, "Scientists have a crucial role to play in pre-college science education reforms. But it is not easy to know how or where to begin" (Alberts, 1991). Experienced practitioners have found that

when scientists and engineers work with master teachers who are able to bridge the partners' world with that of schools and students, the benefits to all collaborators can be tremendous.

Partnerships with parents and the community are essential in systemic science education reform, but to be effective, they must be structured to foster communication.

"There are many reasons for developing school, family, and community partnerships," writes Joyce Epstein (1995). "They can improve school programs and school climate, provide family services and support, increase parents' skills and leadership, connect families with others in the school and in the community, and help teachers with their work. However, the main reasons to create such partnerships is to help all youngsters succeed in school and in later life. When parents, teachers, students and others view one another as partners in education, a caring community forms around students and begins its work."

Inquiry-based science teaching and learning is not familiar to many adults, and they will not understand it until someone takes the time to explain it to them.

Few would argue today that partnerships between schools, parents, and community are unimportant to student success. However, many educators and community members do not necessarily know how to develop valuable, productive programs. Caused and further aggravated by decades of misunderstanding between the parties, educators still do not truly understand the families of the students, families do not understand educators, and "communities do not understand or assist the schools, families, or students" (Epstein, 1995).

A primary focus for involving families and community members in a systemic science education reform program is to help them understand the nature of effective science education. Educators need to show families how new types of science instruction, like that described in CHAPTER 2, differ from the ways in which they learned science. Inquiry-based science teaching and learning is not familiar to many adults, and they will not understand it until someone takes the time to explain it to them.

Some communities have open houses to share concrete examples of inquiry-based instruction and to provide some evidence that the new

methods are proving effective. Others develop family science programs that allow parents to become students again by participating in activities along with their children. Parents will also want to know how the schools plan to evaluate the success of a science education reform program, and how student progress will be documented. As explained in CHAPTER 5, testing is a very powerful part of the system and parents will want their children to do as well, if not better, on their district or state science assessments as before.

Families can and should play an active role in their children's science education, but there is no single best role nor is every role possible for every family. An effective parent involvement program will create a variety of roles. Some of the more active parents might sit on school curriculum and policy committees, collect and organize materials, help arrange parent events, and volunteer in the classroom. Equally important, but less demanding of time, is providing support for their children at home. All of these contributions are valuable.

This may not be easy, given the busy lives of today's parents. Joyce Epstein (1995) writes that single parents and those who are employed outside the home or who live far from the school "are less involved, on average, at the school building unless the school organizes the opportunities for families to volunteer at various times and in various places to support the school and their children." Educators also need to engage parents to help them understand children's lives at home and children's experiences outside of school. Each participant in a collaboration must be committed to making it work; flexibility is part of that commitment.

The keys to effective community-parent-school partnerships are creating new structures, new ways of communicating, and a new sense of shared responsibility. "When parents and community members are truly engaged, they do not just volunteer their time for school activities or drop their opinions in the suggestion box. They initiate action, collaborating with educators to implement ideas for reform...these conversations go beyond the discussion of surface problems and complaints. Through these conversations, people develop the trust and consensus needed for action" (Cortes, 1995).

Partnerships should be developed with awareness of and sensitivity to organizational and cultural differences.

Each institution that is part of a school collaboration has different expectations about the project—the amount of time that will be required or is available to the participants, the technology available to each partner, and what makes for good planning. Partners often use different words to

describe the same phenomenon and have different perceptions of what schools should do. If collaborations are to succeed, these differences need to be discussed and resolved. Even though some of the differences may seem trivial, experienced leaders warn that these are precisely the issues that make or break collaborations.

In some cases, misunderstandings emerge between scientists and teachers. The scientists at Merck, for example, did not realize that teachers had little access to telephones or fax machines. Carlo Parravano explains that it was "a major stumbling block...the corporate world believes that to carry out business you have to have a phone." Due to this misunderstanding, the Merck scientists were put off by the apparent difficulty in reaching the teachers and by the length of time it took teachers to return their calls.

Misunderstandings can emerge from different conceptions of time. Teachers, for example, have fixed schedules and constant interruptions. Curators, academics, scientists, and executives generally exert more control over their days and have longer blocks of uninterrupted time. When discussions about time and scheduling arise, it is essential that each side understands the other's assumptions.

Scientists' and teachers' knowledge, skills, and ways of thinking are often worlds apart and it is easy for them to misunderstand and ultimately mistrust the other's intentions or ability. Over time, with patience and a good facilitator, those misunderstandings can be prevented or clarified. San Francisco's Liesl Chatman remembers showing partners results from an evaluation of a teacher-scientist workshop in which the teachers were fairly positive and the scientists were fairly critical. After reading the reports, the teachers were "shocked and crushed," because they believed the scientists had not enjoyed working with them. The fact that seven out of eight scientists had returned for a second year of partnership suggested otherwise, but the teachers were nonetheless discouraged. Finally, one scientist explained the differing views: "We love working with the program. As scientists we're trained that when 98 percent is working well, we look at the 2 percent that isn't." His partner, a teacher, responded. "We're trained to nurture. When a student gets a 50, we say, 'That's sure better than the 45 you got last month.'" The assumptions that arose naturally from the different groups' cultures nearly scuttled the collaboration. George Miller, a chemist at the University of California, Irvine, acknowledges that "communicating with elementary and even secondary school teachers doesn't come naturally to most scientists" (Barinaga, 1991).

Similarly, perceptual differences can create confusion with parents and community members as well. Language often presents the problem.

Miscommunication between parents and educators can result in substantial resistance to the reform and the *new-fangled* ideas associated with it, even though both groups are genuinely concerned with the welfare of children. Parents recall the vocabulary of their own schooling including the ways they were taught and the culture of the school. When reality clashes with memory, it is reality that has to do the explaining.

For all these reasons, policies and strategies for teacher-parent collaboration should be coupled to some form of communications training for both groups. Without it, teachers may see extended contact with parents as an additional duty and parents may believe they have little to offer the school. "Both groups need opportunities to develop new skills and to enhance their understanding of the potential goals, pitfalls and benefits of partnership" (Parents and schools, 1988).

The leaders of the best programs understand and work with the differences between partners and schools and prepare for those differences. They structure opportunities for communication and facilitate collaborative planning and development of all aspects of the project. Jan Tuomi, a senior program officer at the Center for Education of the National Research Council, oversees a nationwide program that links scientists and teachers. She estimates that without this kind of thoughtful planning and support, three-quarters of all partnerships would fail.

Educators must find ways to institutionalize collaboration.

Many partnerships are "fragile entities that are not institutionalized but depend on good will, trust, and the belief that [they] are a necessary investment in the future and that that they will, indeed, make a difference" (Kubota, 1993). The challenge for collaborations is not only the incremental building of trust and *cultural* understanding, but also to reach beyond these one-on-one relationships to develop organizational trust that outlasts the individuals currently involved. The partners come to feel that they are making an investment in the future. As described in previous chapters, real change takes years—longer than many educators stay in their positions. Even as personnel change, the promise offered by systemic change is that the collaborations will remain in place to welcome new participants.

One strategy for developing lasting collaborations is to ensure that responsibilities are genuinely shared. At the Pacific Science Center in Washington state, Dennis Schatz explains that his staff used to take the initiative in suggesting the next step for the schools. "Now," says Schatz, "the teachers say to them, 'What we really need to do is...' " Schatz is pleased that

the teachers have more responsibility, but he admits that it still is hard to give up control. He expresses the anxiety most partners in a collaboration feel when they recognize that sharing responsibility is the way to go but remain unsure as to how to do it.

Annabelle Shrieve, now at Education Development Center's Center for Science Education, was part of a collaboration in San Francisco that is continuing. She agrees that collaboration could sometimes be difficult. "It was important to communicate and sit down and hash out what we were going to do. Even when it was difficult, though, it was beneficial because the museum, the medical school and the school district all brought resources to the process." As Epstein (1995) writes, "Good partnerships withstand questions, conflicts, debates, and disagreements; provide structures and processes to solve problems; and are maintained—even strengthened—after differences have been resolved."

The final challenge for any partnership is to endure after the initial enthusiasm fades and a particular initiative comes to an end. Programs across the country take a wide variety of approaches, but all try to find ways to institutionalize the best elements of partnership. The Merck Institute for Science Education cannot continue the level of support they are providing for the New Jersey school districts, so they are working with them to ensure that the districts themselves will have the capacity to continue the work. As Carlo Parravano explains, "Merck doesn't do all the workshops. We work with a teacher so she can teach a workshop. We build up one another's capacity."

Because hopes on all sides start out so high, it is commonly difficult for project leaders to envision the lasting impact of their reform initiatives. DeHaan estimates that in 5 years between 150 to 250 elementary teachers in the Atlanta Public Schools will be "imbued with inquiry-based science teaching." Dow in Buffalo is a bit more guarded about his project. "I don't know what a museum can do," he says. "We've got one little toe hold on one little corner of the problem." But Dow still retains hope because he remembers the rewards, "At times you think it's absurd to even attempt to change education. But then you see the kids responding."

The big job never seems completely finished. Time runs out. The startup and developmental money runs out. Of all the jobs that partnerships take on for themselves, the institutionalization of their work is the most uncertain. Yet the likelihood of institutionalizing partnerships is greatly increased if the partners have successfully gained mutual respect, receive mutual benefits, share responsibilities, and believe in the value of their venture. They need to retain those qualities as they go about giving permanence to their work.

As with other components of systemic change, educators continue to search for ways to redefine and improve partnerships. Isolated, one-shot forms of cooperation between formal and informal educational institutions and school districts are giving way to partnerships that direct their combined resources toward developing and sustaining inquiry-based science. Strategies for working with parents, local community organizations, and business have been slower to yield fruit, although practitioners recognize their importance in sustaining reform. "Children's life chances are not likely to get better without collective action in many arenas—the schoolhouse, the local health clinic, the neighborhood, the block, the home, and so on (Comer, 1988; Ascher, 1990)" (NCREL, 1997).

COLLABORATION RECAP

1. Formal partnerships with institutions can be a valuable strategy but must be genuine and carefully planned.
2. Partnerships with parents and the community are essential in systemic science education reform, but to be effective, they must be structured to foster communication.
3. Partnerships should be developed with awareness of and sensitivity to organizational and cultural differences.
4. Educators must find ways to institutionalize collaboration.

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CHAPTER 9

Equity

Current reform initiatives are challenged to ensure that improved science education reaches all students throughout the system—not just those who typically go on to careers in science and mathematics or those who seem bound for college. The National Science Education Standards firmly link equity to high attainment: all students can develop the knowledge and skills described in the Standards "regardless of age, gender, cultural or ethnic background, disabilities, interest or motivation in science" (NRC, 1996).

Practitioners are learning effective strategies for improving different parts of the education system and the system as a whole. However, as they focus on the other parts—curriculum, assessment, planning, professional development, leadership, and partnerships, etc.—they are finding that creating equitable education for all of their students remains a core challenge. Indeed, there is a reciprocal relationship between equity and the systemic reform of science education. Educators cannot successfully attain or accomplish one without the other.

Much is known about the equity challenges facing education today. Educators working on science reforms are raising awareness, working to move from conversation to action, and demonstrating how inquiry-based science education and equity support one another. Still, even as they develop classroom and district practices that hold promise for all students, they are posing difficult questions and continue to look for new answers.

Who Is the "All" in "Science and Mathematics for All"?

Equity has many faces and is often discussed in the context of the interests and needs of various groups. In science and mathematics education in particular, a driving force is the underrepresentation of minority groups and women in professional science and mathematics-related occupations. Consider the following statistics from a National Science Foundation (NSF, 1996) study: African Americans make up 12 percent of the population, but

only 2 percent of employed scientists and engineers. Hispanics compose 9 percent of the population, but only 2 percent of employed scientists and engineers. Women compose more than half of the population, but only 20 percent of employed scientists and engineers. At the same time, there is growing awareness that many students in these groups have neither access nor opportunity to develop scientific and mathematical literacy. This is a sobering picture of the economic and professional future of members of these groups, especially in a job market that increasingly values more specialized knowledge in science and technology and other subjects.

Research shows that there is a difference in achievement between white students and minority students, particularly African Americans and Hispanics. According to the 1992 National Assessment of Educational Progress (NAEP) both African American and Hispanic students "demonstrated significantly lower proficiency than white students" (Mullis et al., 1994). Again, there are many reasons for the disparities. According to Oakes, "Disproportionate percentages of poor and minority students (principally African-American and Hispanic) are using curricula designed for low-ability or non-college bound students. Furthermore, in general, low-income and minority students have less contact with the best qualified science and mathematics teachers" (Oakes et al., 1990).

Another group often included in discussions of equity are students who are considered to have limited English proficiency. Though many bilingual programs exist, students rarely receive science instruction at their appropriate grade level or in their primary instructional language (Mason and Barba, 1992). Furthermore, according to Patricia Stoddart, an associate professor at the University of California, Santa Cruz, "the key issue for language minorities is access to academic content, because most schools focus on teaching [them] English."

Equity issues as they relate to these groups reach far beyond the borders of the school. Societal factors of racism cannot be ignored. Strickland and Ascher suggest that despite "three decades of programmatic change to make schooling for all students integrated and equitable, it is not hard to see continuing instances of both personal and institutional racism in education" (Strickland and Ascher, 1992).

Girls have historically received inadequate attention and encouragement in science. Research shows that they receive less attention than boys in science classrooms, and the attention they do receive is likely to be of lesser quality than that paid to boys (Sadker, Sadker, and Stulberg, 1993; AAUW, 1990). Girls also have less access to materials, have fewer role models in

these fields, and tend to believe that science and mathematics will not be of use to them in the future (Gardner, Mason, and Matyas, 1989; Kahle, 1991). These and other factors contribute to lingering discrepancies in academic achievement. In the early grades, boys and girls' achievement is comparable; by the last year of high school, boys outperform girls in both mathematics and science (Holmes, 1991).

And finally, students who often are overlooked in discussions of equity are those who fall under the heading *special education*. "Creating an inclusive system begins with...goals that apply to all students, as well as...a total policy environment that supports systemic unity...a vision for education which includes ALL students..." (NASBE, 1992).

What Is Equity?

Educators have varied perceptions of what equity is. For some, equity is a powerful set of beliefs about the way people should be treated, and in turn about the way schools should teach children. Their ultimate goal is "classrooms in which all children, whatever their social class, race, national origin, or gender, sit side by side and learn together successfully" (Wilson, 1992). Others view equity as equal distribution of resources. And still others view it not as equal quantity but as equal quality of the educational experience. The notion of equity as "opportunity to learn" includes each of these perspectives. In *Opportunity to Learn: Issues of Equity for Poor and Minority Students*, Stevens and Grymes explain, "...we need to know if students at risk have access to the full range of educational opportunities, what kinds of learning opportunities are provided, and how well-tailored they are to the educational needs of these students" (1993).

While there is a wide spectrum of understanding and beliefs about what equity is, there is little difficulty in recognizing and agreeing on what equity is not. There is much research that describes inequities in schools as well as strategies and programs for responding to such problems. Inequitable practices cover a range of issues including student grouping, segregation, lack of teacher-student identification, low teacher expectations, lack of parental involvement, lack of community support, poor instructional materials, lack of support systems, and undefined goals (McKenzie, 1993).

Equity Relates to Every Part of the System

The earlier chapters of this monograph discussed aspects of the system, but did not focus on equity. Educators often debate whether equity should be addressed as a separate part of a reform program or whether it should be

embedded throughout. They recognize that equity is relevant to every part of the system, but know that unless it is explicitly addressed it can easily be overlooked. Equity lies at the heart of any long-term, systemic change and should relate to all strategies and policies implemented during the process.

Planning for leadership development, professional development, and community outreach should always include participants from all segments of the population.

The chapter on curriculum, for example, described the importance of making quality instructional materials available to all students. But equity in curriculum is more than that. Curriculum frameworks, for example, provide for coherence in the system, consistency from school to school, and assessments that adequately measure achievement (Clune, 1993). A framework that truly addresses equity, however, must also be flexible enough to meet the needs of individual schools, teachers, and students.

The planning and decision making process also should address equity issues. Individuals involved in the development of a curriculum framework, for example, should appropriately represent the interests and diversity of the community and local student population. According to a statement developed by the Equity Action Group of NSF's Statewide Systemic Initiatives, planning for leadership development, professional development, and community outreach should always include participants from all segments of the population (Equity Action Group, 1994).

Equity is almost always present in discussions of testing. Tests currently in place have several significant faults: they do not reflect what practitioners recognize as high-quality science curriculum, they do not align with inquiry-based instructional strategies, and they weaken efforts to improve science education by encouraging teachers to teach to the test. Overall, the quality of education of many students "has been undermined by the nature of the testing problems used to monitor and shape their learning" (Darling-Hammond, 1994). New assessment instruments must avoid bias, connect appropriately with curriculum and teaching, and not rely on skills that favor any particular group (Darling-Hammond, 1994; Rothman, 1994).

Instructional practices such as tracking are controversial because of the equity questions they raise. In the past, decisions to follow tracking practices were based on the assumption that less capable students would suffer if

grouped with brighter students, and that tracking placements were accurate and fair (Oakes, 1990). There is evidence on both sides about the utility of tracking as an education strategy, but there is no question that tracking as it is implemented today is not fair (Bates, 1992). Disproportionate numbers of minority and disadvantaged students are placed in lower track classes (Oakes and Lipton, 1992), which in turn often denies them equitable access to quality teachers and materials (Oakes et al., 1990; Gamoran, 1992).

Even when practices address equity-related concerns, policies are slow to change. From an organizational perspective, practices related to tracking, for example, can translate into inequities across a whole district. Educators at the Harvard Graduate School of Education (1992) stated, "one of the most disturbing aspects of the tracking issue is its potential to divide communities along racial and social class lines." Student assignment policies that group students in particular schools or clusters within schools (such as desegregation practices, and design of bilingual and gifted and talented program) raise serious questions about equity and fairness.

Supporting Equitable Classroom Practice

CHAPTER 2 describes a vision for high-quality science education. The promise of this vision is that inquiry-based science education does more than facilitate meaningful science learning—it makes science learning accessible to all students. Inquiry-based science deals with familiar subject matter, uses materials that children can touch and see, and creates an environment in which students of all backgrounds are motivated to learn and can achieve. Sandy Lam in San Francisco explains, "Science might be the one thing that piques the natural curiosity of all children." Classrooms that emphasize memorizing facts and *cookbook* experiments deprive all students of these opportunities.

Inquiry-based science education also develops skills and knowledge valuable for all subject areas. The National Science Education Standards, for example, describe teaching practices that "adapt and design curricula to meet the interests, knowledge, understanding, abilities and experiences of students" and that "challenge students to accept and share responsibility for their own learning" (NRC, 1996). The standards also describe the importance of engaging in discourse about science concepts, making connections between evidence and explanations, and recognizing and analyzing alternative explanations and models. These are essential parts of learning science, but just as importantly, they are essential for learning in general and functioning productively and successfully in the world.

Moving from Conversation to Action

Science educators engaged in reform have spent many hours talking about the problems and issues surrounding equity. The first challenge has been to recognize and raise awareness about equity in science education and throughout the education system. It is now time to translate the conversation into action. Experienced practitioners who are serious about reform are experimenting with a wide range of strategies and policy changes such as curriculum adoptions that move from textbooks to hands-on instructional materials; using new forms of assessment; promoting practices in which all students learn together; forging alliances among schools, families, and communities; and holding practitioners and schools accountable for both quality and equity (Oakes et al., 1990).

As these practitioners are learning, any single one of these efforts by itself is not powerful enough to move the system as a whole forward. The earlier chapters of this monograph discussed strategies for improving various aspects of the system, but it is most important that educators energize all parts of the system to work together. Much has been learned already, but we are still working to ensure a "democratic, fully equitable and accessible system of education" (Perrone, 1987).

Linn (1993) suggests that equity in science and mathematics education is an issue both of fairness and of national interest. Regardless of the reason, the education reform community is committed to the idea that all students should have equitable access to quality science and mathematics education. And as Perrone (1987) wrote, "We can do this by asking hard questions, challenging simple answers, creating and risking the implementation of new structures...We need to encourage louder voices from many more of our school administrators, teachers, students and parents...The struggle for educational and social equity is nothing less than an important responsibility for all educators."

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Suggested Reading

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CHAPTER 10

Postscript

We hope readers of this monograph have learned something of both the complexity and excitement of planning and implementing an inquiry-based science education program. It is a long-term challenge that requires attention to every component of the education system.

All parts of the system are equally important: planning, leadership, curriculum, instruction, assessment, professional development, financing, collaboration, and equity. We have highlighted them because we believe the lessons learned by those already working in the field can inform the programs and policies of those newer to the process of science reform.

Unfortunately, this monograph is not as comprehensive as we might like. Some important issues such as making science part of the core curriculum, the use of technology, classroom assessment, large-scale evaluation, and linking teacher preparation to reform efforts have been omitted. There are others mentioned below and still more that may have eluded us. In reality, these topics could have been chapters in their own right. We omitted them in favor of others that seem to have yielded greater levels of understanding that we could pass on to you, the reader. Nevertheless, we mention these topics in hopes that you will forge new levels of understanding in your quest to make inquiry-based science instruction the norm in your school or district.

Accepting science as part of the school district's core curriculum.

In districts that consider science a core subject area, all students have access to rich and varied curriculum materials within blocks of time that are adequate for engaging in rigorous inquiry-based instruction. Unfortunately, this is far from the norm in many school systems, largely because teachers are expected to concentrate on those subjects that appear on large-scale tests—primarily language arts and mathematics. As a result, science often slips through the cracks.

In spite of the incentive system borne through high-stakes testing, there are districts that make science programs a high priority. We need to better understand the vision and practices of these school districts in order to develop strategies that might work elsewhere.

Using technology as an effective tool for science instruction and reform.

Educators increasingly recognize that advances in technology have the potential to revolutionize the way science is taught and learned in U.S. schools. Across the country, school systems are allocating substantial amounts of money to buy computers and software, to network their classrooms, and to train teachers in the use of these technologies. School teachers are becoming more comfortable using the Internet to supplement other classroom work, and they are introducing students to different programs now available for creating databases and for analyzing scientific data.

Despite this increase in the availability of technology, very few districts have effectively formed a vision of how to integrate technology into systemic reform efforts. This is particularly true at the elementary school level. There are interesting experiments taking place across the country, many supported by the National Science Foundation, that have shown profound promise for change. But, on the whole, in the science education programs most familiar to us, students and teachers are still struggling to closely align the use of technology to science frameworks, standards, and goals for reform.

Improving teacher content knowledge to provide strong science instruction.

Effective teaching in any subject requires a strong base of knowledge in that subject area as well as knowledge of strategies for instruction and assessment. Unfortunately, many elementary teachers are poorly prepared in science. Districts have to recognize and address this problem if they hope to give all students the background knowledge they need to succeed in high school science courses.

Teacher support and assistance from practicing scientists is one valuable approach to addressing this lack of preparation and the resulting lack of confidence in teaching science. In order to effectively implement the science standards, districts will have to make the improvement of teacher content knowledge a high priority on the professional development agenda. We have seen pilot efforts that look promising; they need time for nurturing and growth.

Strengthening teacher preparation programs in order to improve elementary science instruction.

Lack of science content knowledge is linked closely to inadequate preparation for teachers in universities and colleges across the country. This, together with higher education's slow pace of change in preparing teachers to meet the needs of an increasingly diverse student population, has produced a teacher corps with only a small repertoire of the skills necessary for teaching inquiry-based science in today's classrooms. Closer collaboration between higher education and the public schools is essential if colleges and universities are to offer preservice and inservice education that advances the new science standards and frameworks.

Expanding initiatives for K-16 articulation in science education.

With the development of new science standards and the evolving efforts at designing new assessment approaches for science, there is increasing consensus about what students should know and be able to do at different levels of the education system. The alignment of these expectations with curricula in a coherent sequence from the primary grades through the undergraduate college years—known as K-16 articulation—is now a more attainable goal than at any time in the past. Achieving it, however, will require collaboration, trust, and mutual respect among educators from kindergartens to universities. We see strong potential for more consistent and ongoing articulation in science education.

Conducting large-scale evaluations of science education programs.

School districts are increasingly implementing reforms in science education within the context of comprehensive systemic change efforts. This leads to many questions about how to evaluate the success of these programs. Systemic change is a long-term effort that requires simultaneous restructuring of many different facets of school life and organization. Measuring the progress of this kind is difficult, especially in the early stages.

Large-scale evaluations are generally most useful when several assessment methods are employed in combination with each other. One of the most important methods is the analysis of student test data, but this measure should be thoughtfully supplemented with other short-term and long-term indicators of success, including longitudinal research on the participation rates of students in upper level science courses once they reach high school and college. This kind of research takes both time and money, but it is an

indicator that science education reform has achieved its ultimate goal—lasting change in student learning and performance.

Those who have climbed the steep slopes of science education reform find reward in the breathtaking panorama below, but know they must climb higher still. Surely, there is much left to do. These issues and others will be the subject of many ongoing conversations about science reform in our individual schools and districts over the next several years and within this monograph series. But from where we stand today, we know how much has been accomplished in the last decade. Although not yet at the summit, we have reason to be optimistic.

APPENDIX

Resources for Science Education Reform

Local Systemic Change Districts[1]

Alabama

Hands-On Activity Science Program
Principal Investigator: John Wright
Institution: University of Alabama–Huntsville
Institute for Science Education
Morton Hall Room 112
Huntsville, AL 35899
Phone: (205) 895-6670
Email: mossp@email.uah.edu
Co-Principal Investigators: Charles W. Shipp, Joanna May, Linda Sanders and J.A. Childers
Coverage: 5 districts; 37 schools; 620 teachers; 13,600 students

Alaska

Earth Systems Implementation Project (ESIP)
Principal Investigator: Judy Reid
Institution: Bartlett High School
Curriculum and Instruction
25-500 N. Muldoon Rd. Rm C222
Anchorage, AK 99506-1698
Phone: (907) 269-8341
Email: reid_judy@msmail.asd.k12.ak.us
Co-Principal Investigators: John Sibert and Donna York
Coverage: 1 district; 61 schools; 1,050 teachers; 28,000 students

Arizona

Mesa Systemic Initiative
Principal Investigator: Susan Sprague
Institution: Mesa Public Schools/SSRC
143 South Alma School Road
Mesa, AZ 85210-1096
Phone: (602) 898-7815
Email: ssprague@barnum.mesa.k12.az.us
Co-Principal Investigators: Douglas Barnard and Susan Wyckoff
Coverage: 1 district; 58 schools; 2,000 teachers; 48,050 students

California

Teacher Enhancement for Student Success (TESS)
Principal Investigator: Charles McCully
Institution: Fresno Unified School District
Office of Superintendent
Tulare and M Street
Fresno, CA 93721
Phone: (209) 441-3515
Email: robert_grobe@csu.fresno.edu
Coverage: 1 district; 79 schools; 2,040 teachers; 58,400 students

[1] The following districts are implementing science education reform projects with support of the National Science Foundation's Local Systemic Change through Teacher Enhancement program. This list is provided as a resource for those districts that are planning reform efforts and wish to consult with others.

Leadership Institute for Teaching Elementary Science (LITES)
Principal Investigator: Jane Bowyer
Institution: Mills College
Department of Education
5000 MacArthur Boulevard
Oakland, CA 94613
Phone: (510) 430-2118
Email: jane@ella.mills.edu
Co-Principal Investigators: Carolyn Getridge
Coverage: 1 district; 60 schools; 1,050 teachers; 52,000 students.

CITY SCIENCE–University of California, San Francisco Institute for Elementary Teachers
Principal Investigator: Peter Walter
Institution: University of California–San Francisco
Science & Health Educ Partnership
100 Medical Center Way
W-1, Top Floor–Box 0905
San Francisco, CA 94143-0905
Phone: (415) 476-0930
Email: peter_walter.biochem@quickmail.ucsf.edu
Co-Principal Investigators: Bonnie Smith and Elizabeth Chatman
Coverage: 1 district; 76 schools; 1,300 teachers; 32,500 students.

National School District Systemic Teacher Enhancement Project (NSSTE)
Principal Investigator: Paul Saltman
Institution: University of California, San Diego
Department of Biology
9500 Gilman Drive, Dept. 0176
La Jolla, CA 92093-0176
Phone: (619) 534-3824
Email: robert_dean@unexpost.ucsd.edu
Co-Principal Investigators: Christopher Oram, George Cameron and Robert A. Dean
Coverage: 1 district; 10 schools; 410 teachers; 6,639 students.

Language Acquisition in Science Education for Rural Schools (LASERS)
Principal Investigator: Patricia Stoddart
Institution: University of California–Santa Cruz
Education Board of Studies–Merrill College
1156 High Street
Santa Cruz, CA 95064
Phone: (408) 459-3850
Email: stoddart@cats.ucsc.edu
Co-Principal Investigators: Lucinda Pease-Alvarez and Roberta Jaffe
Coverage: 7 districts; 50 schools; 1,272 teachers; 30,000 students.

Georgia

Teacher Enhancement Through Elementary Science Education Partners (ESEP)
Principal Investigator: Robert DeHaan
Institution: Emory University
Medical School
Dept. of Anatomy & Cell Biology
Atlanta, GA 30322
Phone: (404) 727-6237
Email: bob@anatomy.emory.edu
Co-Principal Investigators: Benjamin O. Canada, Molly Weinburgh, and L. Vernon Allwood
Coverage: 1 district; 72 schools; 1,600 teachers; 30,000 students.

Indiana

Building Bridges to the Future: The Next Generation of Science-Enabled Elementary School Teachers
Principal Investigator: Susan Johnson
Institution: Ball State University
College of Sciences & Humanities
NQ 112
Muncie, IN 47306
Phone: (317) 285-8831
Email: 00smjohnson@bsuvc.bsu.edu
Coverage: 14 districts; 40 schools; 650 teachers; 13,000 students.

Michigan

Midland Public Schools Systemic Change Teacher Enhancement Institute

Principal Investigator: Sarah Lindsey
Institution: Midland County Intermediate Science Resources Center
815 State Street
Midland, MI 48640
Phone: (517) 839-2427
Email: jpegel@aol.com
Co-Principal Investigators: Jody S. Pagel and Kathy A. Grzesiak
Coverage: 1 district; 12 schools; 308 teachers; 5,900 students.

Montana

KEYSTONE: A Rural Regional Training Program for Excellence in Science and Technology

Principal Investigator: Myra Miller
Institution: Bozeman Public Schools
Willson Science and Tech School
404 West Main Street
Bozeman, MT 59715
Phone: (406) 585-1500
Email: wimill@hawks.bps.montana.edu
Co-Principal Investigators: Ned Levine and Terry Baldus
Coverage: 23 districts; 48 schools; 518 teachers; 6,300 students.

Nevada

The Mathematics and Science Enhancement II (MASE II)

Principal Investigator: P. Kay Carl
Institution: Clark County School District
2832 East Flamingo Road
Las Vegas, NV 89121-5207
Phone: (702) 799-5474
Email: gregg@nevada.edu
Co-Principal Investigators: Linda Gregg
Coverage: 1 district; 60 schools; 2,040 teachers; 46,000 students.

New Jersey

The Partnership for Systemic Change: A School/Business Collaborative to Enhance Science, Mathematics, and Technology Teaching and Learning

Principal Investigator: Carlo Parravano
Institution: Merck Institute of Science Educ.
126 East Lincoln Ave.
P.O. Box 2000 (RY7-230)
Rahway, NJ 07065-0900
Phone: (908) 594-7401
Email: parravano@merck.com
Co-Principal Investigators: Christine Salcito, Kate Fischer, David Decker, and Walter Tylicki
Coverage: 4 district(s); 35 school(s); 825 teachers; 23,100 students.

Great Ideas in Science Consortium: Partners for Integrated Science Curriculum Reform

Principal Investigator: Jacqueline Willis
Institution: Montclair State College
Great Ideas in Science Consortium
Valley Road & Normal Avenue
Montclair, NJ 07043
Phone: (201) 893-4000
Email: giacalone@aol.com
Co-Principal Investigators: Gloria Scott, Maria Cannizzaro, Jane McMillan-Brown, and Bonnie K. Lustigaman
Coverage: 2 districts; 44 schools; 1,000 teachers.

$E=MC^2$

Principal Investigator: Linda Walker
Institution: West Windsor/Plainsboro RSD
Curriculum and Instruction
505 Village Rd. West
P.O. Box 248
Princeton Junction, NJ 08550
Phone: (609) 799-0200
Email: wwpcur@pluto.njcc.com
Co-Principal Investigators: Edward Nartowitz and Sondra Markman
Coverage: 3 district(s); 15 school(s); 574 teachers; 13,550 students.

New York

TEAM 2000

Principal Investigator: Peter Dow
Institution: Buffalo Museum of Science
1020 Humboldt Parkway
Buffalo, NY 14211-1293
Phone: (716) 896-5200
Email: team@mailgate.drew.buffalo.k12.ny.us
Co-Principal Investigators: Samuel J. Alessi, Jr., and Delcene West
Coverage: 1 district; 61 schools; 1,400 teachers.

"SMART PROCESS"–Local Systemic Change Through Teacher Enhancement

Principal Investigator: Gilbert Turchin
Institution: Community School Districts 3 & 5
300 West 96th Street
New York, NY 10025
Phone: (212) 678-2918
Email: csd3@chelsea.ios.com
Co-Principal Investigators: Howard Berger and Howard Nadler
Coverage: 2 districts; 35 schools; 1,470 teachers; 21,535 students.

Ohio

Project SEEDS: Science Education Enhancing the Development of Skills, K-6

Principal Investigator: Jane Hazen
Institution: The Educational Enhancement Partnerships (TEEP)
Stark County School District
2100–38th Street, N.W.
Canton, OH 44707-2300
Phone: (216) 492-8136
Email: jbh2sc@bigbird.stark.k12.oh.us
Coverage: 16 public & 3 private districts; 76 schools; 1,000 teachers; 30,000 students.

Pennsylvania

ASSET Teacher Enhancement Project

Principal Investigator: Reeny Davidson
Institution: ASSET, Inc.
15 Terminal Way
Pittsburgh, PA 15219-1299
Phone: (412) 488-1444
Email: davisonr@duq3.cc.duq.edu
Co-Principal Investigators: Vincent Valicenti, Margie Ritson, Jacqueline Coleman, Greg Calvetti, Kalyani Raghavan, and Frances Alder
Coverage: 15 districts; 1,020 teachers; 25,000 students.

Rhode Island

The KITES Project: Kits In Teaching Elementary Science

Principal Investigator: Greg Kniseley
Institution: Rhode Island College
Dept. of Elementary Education, HM 205
600 Mount Pleasant Avenue
Providence, RI 02908-1991
Phone: (401) 456-8016
Email: mkniseley@grog.ric.edu
Co-Principal Investigators: Gerald Kowalczyk
Coverage: 8 districts; 52 schools; 600 teachers; 12,000 students.

Tennessee

Metro Nashville Public Schools Systemic Initiative to Improve Science Achievement for All Students

Principal Investigator: Barbara Nye
Institution: Tennessee State University
Center of Excellence for Research
and Policy on Basic Skills
Nashville, TN 37209
Phone: (615) 963-7231
Email: bnye@picard.tnstate.edu
Co-Principal Investigators: Richard Benjamin and Emily Stinson
Coverage: 1 district; 84 schools; 3,000 teachers; 70,000 students

Washington

STAFF Leadership for Rural School Districts

Principal Investigator: Denis Schatz
Institution: Pacific Science Center Fdn.
Department of Education
200 Second Ave. North
Seattle, WA 98109-4895
Phone: (206) 443-2867
Email: schatz@pacsci.org
Coverage: 3 districts; 8 schools; 193 teachers; 6,139 students.

Hands-On Science in Seattle Schools, K-5

Principal Investigator: Arlene Ackerman
Institution: Seattle Public Schools
815 Fourth Avenue, North
Seattle, WA 98109
Phone: (206) 298-7180
Email: aackerman@is.ssd.k12.wa.us
Co-Principal Investigators: Leroy Hood, Martha Darling, Charles Laird and Roger Bumgarner
Coverage: 1 district; 70 schools; 1,400 teachers; 23,000 students.

School Districts Referenced in this Document

Anchorage, AK

Judy Reid
Bartlett High School
Curriculum and Instruction
25-500 N. Muldoon Rd. Rm C222
Anchorage, AK 99506-1698
Phone: (907) 269-8341
Email: reid_judy@msmail.asd.k12.ak.us

Atlanta, GA

Robert DeHaan
Emory University
Medical School
Dept. of Anatomy & Cell Biology
Atlanta, GA 30322
Phone: (404) 727-6237
Email: bob@anatomy.emory.edu

Baltimore, MD

Andrea Bowden
Supervisor, Office of Science, Mathematics, and Health
Baltimore City Public Schools
200 East North Avenue
Baltimore, MD 21202
Phone: 410-396-8573

Buffalo, NY

Cathy Chamberlin
Project Administrator—TEAM 2000
BPS Curriculum Department
229 Floss Avenue
Buffalo, NY 14215
Phone: 716-897-8131
Email: crchamb@aol.com

Cambridge, MA

Melanie Barron
Science Coordinator, K-12
Cambridge Public Schools
CRLS – 459 Broadway
Cambridge, MA 02138
Phone: 617-349-6792
Email: crlsbarron@aol.com

Cleveland, OH

Lawanna White
Science Supervisor
Cleveland Public Schools
1380 E. 6th Street
Room 225
Cleveland, OH 44114
Phone: 216-574-8180

Huntsville, AL

Arlene Childers
Associate Director
Institute for Science Education
University of Alabama, Huntsville
Wilson Hall 107
Huntsville, AL 35899
Phone: 205-890-6156

Las Vegas, NV

Linda Gregg
K-5 Mathematics and Science Specialist
851 E. Tropicana
Paradise Room 22
Las Vegas, NV 89119
Phone: 702-799-1997
Email: lgregg@intermind.net

Mesa, Arizona

Susan Sprague
Mesa Public Schools/SSRC
143 South Alma School Road
Mesa, AZ 85210-1096
Phone: (602) 898-7815
Email: ssprague@barnum.mesa.k12.az.us

New York, NY

Howard Nadler
Science Coordinator
Community School District 5
433 West 123rd Street
New York, NY 10027
Phone: 212-769-7552
Email: hnadler@ralphbunche.rbs.edu

John Cafarella
Director of Science
Community School District 6
4360 Broadway
New York, NY 10023
Phone: 212-795-8032
Email: SyYentz@aol.com

Howard Berger
Director of Science Education
Community District 3
270 West 70th Street
New York, NY 10023
Phone: 212-663-8713

Pasadena, CA

Jennifer Young
Coordinator K-8 Science
Pasadena Unified School District
2501 Page Drive
Pasadena, CA 91001
Phone: 818-791-8932
Email: jyure@capsi.edu

Pittsburgh, PA (Allegheny Schools)

Reeny Davison
ASSET, Inc.
15 Terminal Way
Pittsburgh, PA 15219-1299
Phone: 412-488-1444

San Francisco, CA

Mathematics and Science Program Director
Curriculum Improvement and Professional Development Center
2550 25th Avenue
San Francisco, CA 94116
Phone: 415-759-2950

Helpful Organizations

The Annenberg/CPB Math and Science Project
901 E Street NW
Washington, DC 20004
(202) 879-9600

Association of Science Materials Centers (ASMC)
Susan Sprague
Science Materials Center
Mesa Public Schools
143 South Alma School Road
Mesa, AZ 85210-1096

Association of Science-Technology Centers
1025 Vermont Ave. NW
Suite 500
Washington, DC 20005
(202) 783-7200

Center for Urban Science Education Reform
Judith Opert Sandler
Education Development Center
55 Chapel Street
Newton, MA 02158-1060
(617) 969-7100 X2409

The Exploratorium Institute for Inquiry
Lynn Rankin
3601 Lyon Street
San Francisco, CA 94123
(415) 563-7337

National Research Council, Center for Science, Mathematics, and Engineering Education
2101 Constitution Ave NW
Washington, DC 20418
(202) 334-2353

National Science Resources Center
Director of Outreach
Capital Gallery
600 Maryland Avenue SW
Suite 880
Washington, DC 20024
(202) 287-2063

New Standards Project
Learning Research and Development Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15260
(412) 624-8319

TERC, Cheche Konnen Center for Science Education Reform
Ann Rosebery
2067 Massachusetts Avenue
Cambridge, MA 02140
(617) 547-0430

Women's Educational Equity Act Publishing Center
Education Development Center
55 Chapel Street
Newton, MA 02158
(617) 969-7100

Center for Urban Science Education Reform (CUSER) Key Contact Names[2]

Baltimore, MD
Andrea Bowden
Supervisor, Office of Sci., Math & Health
Baltimore City Public Schools
200 East North Avenue
Baltimore, MD 21202
Phone: 410-396-8573
Fax: 410-396-8063

Beaumont, TX
Patsy Magee
Science Supervisor, K-12
BISD Administration Bldg
3395 Harrison
Beaumont, TX 77706
Phone: 409-899-9972, ext. 259
Fax: 409-899-5892
Email: patsy@beaumont.isd.tenet.edu
Martha Roberts

Buffalo, NY
Cathy Chamberlin
Project Administrator–Team 200
BPS Curriculum Dept.
229 Floss Avenue
Buffalo, NY 14215
Phone: 716-897-8131
Fax: 716-897-8121
Email: crehambl@aol.com

Cambridge, MA
Melanie Barron
Science Coordinator K-12
Cambridge Public Schools
CRLS–459 Broadway
Cambridge, MA 02138
Phone: 617-349-6792
Fax: 617-349-6318
Email: crlsbarron@aol.com

Cleveland, OH
Lavanna White
Science Supervisor
Cleveland Public Schools
1380 E. 6th Street
Room 255
Cleveland, OH 44114
Phone: 216-574-8180
Fax: 216-574-8132

Fort Wayne, IN
Dana Wichern
Curriculum Coordinator
Fort Wayne Community Schools
1200 South Clinton Street
Fort Wayne, IN 46802
Phone: 219-425-7255
Fax: 219-425-7722

Jackson, MS
Exec. Dir. of Instruction/Student Lrng.
662 South President Street
POB 2338
Jackson, MS 39201
Phone: 601-960-8762
Fax: 601-973-8551

Las Vegas, NV
Linda Gregg
K-5 Math & Science Specialist
851 E. Tropicana
Paradise Room 22
Las Vegas, NV 89119
Phone: 702-799-1997
Fax: 702-799-5687
Email: lgregg@intermind.net

Lexington, KY
David Taylor
Science Coordinator
Fayette County Schools
701 East Main Street
Lexington, KY 40502
Phone: 606-281-0240
Fax: 606-281-0106
Email: dtaylor@msmail.fayette.k12.ky.us

[2] The following districts have participated in CUSER's activities that provide opportunities for school systems involved in science education reform to improve their programs by learning from each other.

New York, NY District 3
Howard Berger
Director of Science Education
NYC Community School District 3
270 West 70th Street
New York, NY 10023
Phone: 212-663-8713
Fax: 212-932-3883

New York, NY District 5
Howard Nadler
Science Coordinator
Community School District 5
433 West 123rd Street
New York, NY 10027
Phone: 212-769-7552
Fax: 212-932-3109
Email: hnadler@ralphbunche.rbs.edu

New York, NY District 6
John Cafarella
Director of Science
Community School District 6
4360 Broadway
New York, NY 10033
Phone: 212-795-8032
Fax: 212-795-9611
Email: SyYentz@aol.com

Pasadena, CA
Jennifer Yure
Coordinator K-8 Science
Pasadena Unified School District
2501 Page Drive
Pasadena, CA 91001
Phone: 818-791-8932
Fax: 818-791-7434
Email: jyure@capsi.edu

San Francisco, CA
Sandra Lam
Math & Science Program Director
Curric. Improvement & P.D. Ctr
2550 25th Avenue
San Francisco, CA 94116
Phone: 415-759-2950
Fax: 415-759-2903

South Bend, IN
Jesse Warren
Curriculum Facilitator
South Bend Community School Corp.
635 South Main Street
South Bend, IN 46601
Phone: 219-283-8057
Fax: 219-283-8059
Email: jwarren@sbcsc.k12.in.us

Spring Branch, TX
Dee Goldberg
Elem. Coord. for Sci. & Tech
Spring Branch ISD
955 Campbell Road
Spring Branch, TX 77024
Phone: 713-464-1511, ext. 2326
Fax: 713-365-4881
Email: goldberd@spring.branch.isd.tenet.edu

Springfield, MA
Diane Putt
Supervisor of Science
195 State Street
Box 1410
Springfield, MA 01102-1410
Phone: 413-787-7230
Fax: 413-787-7211

Worcester, MA
Joyce Gleason
Science Curriculum Liaison
Worcester Public Schools
20 Irving Street
Worcester, MA 01609
Phone: 508-799-3592
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